Physical and Mechanical Properties of Bamboo Particleboard using Dextrin-citric Acid as Adhesive

Ragil Widyorini[1], Greitta Kusuma Dewi[1], Arif Nuryawan[2] and Eka Mulya Alamsyah[3]
[1]*Forestry Faculty, Universitas Gadjah Mada, Yogyakarta, Indonesia*
[2]*Forestry Faculty, Universitas Sumatera Utara, Medan, Indonesia*
[3]*School of Life Sciences and Technology, Institut Teknologi Bandung, Bandung, Indonesia*

Keywords: Bamboo Particleboard, Dextrin-Citric Acid, Mechanical Properties, Physical Properties.

Abstract: Dextrin-citric acid adhesive is predicted to be a promising natural adhesive of particleboard. Different types of dextrin may affect the performance of wood bonding. The aim of this research was to investigate the effect of dextrin types and the ratio of dextrin/citric acid on the physical and mechanical properties of particleboard made of petung bamboo (*Dendrocalamus asper*). Two kinds of dextrin-based materials, i.e. maltodextrin and durian seed dextrin were applied in this research. The dextrin/citric acid ratios were set at 100/0, 75/25, and 50/50 wt%. The particleboards were made in 25 cm x 25 cm x 1 cm size, with target density and adhesive content were set at 0.75 g/cm³ and 15 wt% based on the dried weight of particles, respectively. A three-step press cycle method was used for particle board manufacturing and the press condition was set at 200°C for 10 minutes. The result showed that particleboard with maltodextrin-based adhesive has better properties than particleboard with durian seed dextrin-based adhesive. The best properties of particleboard were achieved by maltodextrin/citric acid adhesive at the ratio of 50/50 wt%. Those properties could meet the requirement of Japanese Industrial Standard (JIS) A 5908 (2003) for particleboard. In addition, this research indicated that durian seed dextrin can be improved as adhesive for particleboard.

1 INTRODUCTION

Dextrin is a product derived from starch, which produced by starch degradation process that usually uses heat and a hydrolyzing agent such as acids, acid producing chemicals, enzyme or other catalyst (Kollman et al., 1975). It was referred to a group of hydrophyllic polysaccharides consisting of D-glucose units linked by 1,4-glycosidic bonds with shorter saccharide-chain than starch (USDA, 2011). The raw material of dextrin (i.e. starch) was environmental friendly, renewable resource, low cost and abundant available in various types (Kennedy, 1989). Corn starch, waxy maize starch, wheat starch, as well as rice starch were native starches that can produce dextrins. Dextrin has low viscosity due to their low molecular weight and also has properties that is partially- completely soluble in water but practically insoluble in ethanol (95%), propan-2-ol and chloroform (Hassid, 1993; Merck Index, 2006; Rowe et al., 2009). Its properties were potential to be developed as adhesives and the most dextrins were used as adhesives for paper products or as food additive (BeMiller, 2003; Radley, 1976). Kollman et al., (1975) stated that dextrins could not be a satisfactory wood adhesive because of the low bonding capacity. Some researchers used cross linker like citric acid to improve the bonding capacity of dextrin for glass paper and wood bonding purposes (Castro-Cabado et al., 2016; Santoso et al., 2017). The physical and mechanical properties of dextrin-based particleboard were proven to be increased by citric acid addition (Santoso et al., 2017). Citric acid was known to be able to increase particle size.

There are various types of dextrin, but the easiest type to find is maltodextrin. Maltodextrin is a dextrin that has average chain length of 3-20 glucose units and pH 4.5-6.5 (Dokic et al., 1998; Rowe et al., 2009). Maltodextrin had been used as wood adhesive with citric acid addition in Nipa particleboard manufacturing at 100/0~0/100 wt% maltodextrin/citric acid ratios. Addition of 25 wt% bonding strength value and decrease almost 50% of

Widyorini, R., Dewi, G., Nuryawan, A. and Alamsyah, E.
Physical and Mechanical Properties of Bamboo Particleboard using Dextrin-citric Acid as Adhesive.
DOI: 10.5220/0010205200002775
In *Proceedings of the 1st International MIPAnet Conference on Science and Mathematics (IMC-SciMath 2019)*, pages 475-480
ISBN: 978-989-758-556-2

the board's thickness swelling and water absorption values from the adhesive without citric acid addition at 200°C pressing temperature (Santoso et al., 2017).

Besides maltodextrin, there is also dextrin from durian seed starch that may be potentially developed. Durian seed waste and its starch have not been widely used yet, instead of their potential availability on Indonesia. Some researchers had studied the potential uses of durian seed waste and its starch for animal feeds, food filler, biodegradable film and pharmaceutical industry (Ho & Bhat, 2015; Malini et al., 2016; Pimpa et al., 2012; Siriphanich, 2011; Sugiarto & Toana, 2018), but the dextrin have not been studied yet. The dextrinization of durian seed starch was expected to increase its properties and utilization. Two types of dextrin (maltodextrin and durian seed dextrin) were expected to have different effect on wood bonding. This research was aimed to study the effect of dextrin types and dextrin/citric acid ratio on the physical and mechanical properties of particleboard made of petung bamboo (*Dendrocalamusasper*).

2 MATERIALS AND METHODS

2.1 Materials

Petung bamboo (*Dendrocalamus asper*) particles were collected from Sleman district, Yogyakarta province, Indonesia. The particles passed through 10 mesh screen with the moisture content around 12% were used as raw material. Maltodextrin with dextrose equivalent (DE) 10-15 were purchased from Zhucheng Dongxiao Biotechnology Co. Ltd, China without further purification. Durian seed dextrin was obtained by dextrinization of durian seed starch in acid hydrolysis. The durian seed was collected from Medan, North Sumatra, Indonesia. The dextrinization method was done by making durian seed starch into suspension with 30% concentration based on dried weight before adding HCl until its pH was 1, then it was liquidated at 95°C for 35 minutes, neutralized by NaOH, oven-dried at 50°C for 2 days and pulverized into 80 mesh size. Citric acid (anhydrous) was purchased from Brataco Ltd, Indonesia without further purification.

2.2 Methods

2.2.1 Preparation of the Adhesive Solution

All of the adhesive solutions were made in the concentration of 50 wt%, except the durian seed dextrin/citric acid ratio (100/0) that used dextrin-solvent ratio of 1:20 (w/v) for good spraying. The dextrin and citric acid was dissolved in hot water (70°C±2°C). The mixture ratios of dextrin/citric acid were set at 100/0, 75/25, and 50/50wt%.

2.2.2 Manufacturing of Particleboard

The adhesive solution (45°C ± 2°C) was spreaded on the surface of the bamboo particles using spraying method. The adhesive content of the solution was 15 wt% based on the air-dried particles weight. The moisture contents of the sprayed particles were then reduced to 2-4% by oven-drying for good inter-particles bonding. The particles were then hand-formed into a mat with 25 cm x 25 cm size using forming box. The mat was hot-pressed using 3-step press cycle method as done by Widyorini et al. (2018). The mat was hot-pressed for 5 minutes in first-step cycle, followed by breathing process (hot-press release) for 1 minutes in second-step cycle, and then another 5 minutes hot-press in third-step cycle (the total pressing time was 10 minutes). The hot- press was set at 200°C in the specific pressure of 3 MPa. The target size and target density were 25 cm x 25 cm x 1 cm and 0.75 g/cm³, respectively. After hot press process, the boards were then stored/conditioned for ± 7 days at room temperature before the board properties evaluation.

2.2.3 Evaluation of Board Properties

Evaluation of boards properties used Japanese Industrial Standard (JIS) A 5908 (2003) as the standards of sample sizes, test method and board quality classification. The boards properties evaluated in this research were density (D), moisture content (MC), thickness swelling (TS), water absorption (WA) and surface roughness (SR) for physical properties, as well as, internal bonding strength (IBS), modulus of rupture (MOR), and modulus of elasticity (MOE) for mechanical properties. D, MC, TS, WA and IBS were tested using sample in 5 cm x 5 cm size, while MOR-MOE was tested using sample in 20 cm x 5 cm size. D was determined by dividing the weight of the sample with its volume, while MC was determined by dividing the weight change of the sample after oven-drying with its oven-dried weight (based on the percentage). TS and WA were determined by the percentage of thickness change and weight change of samples after 24 hours water-immersion at room temperature based on initial thickness and weight of the sample. SR test was measured with surface roughness tester SRG 4000 (Bosworth Instrument, Cleveland, USA). IBS was determined after a sample was failed (splitted in the middle) at maximum tension (vertically to board face) with the rate of 2 mm/min. MOR and MOE were tested with giving load vertically on board face at 10 mm/minute rate and 150 mm span until maximum load before cracking.

3 RESULTS AND DISCUSSIONS

All boards were manufactured successfully without any delamination, although the board densities could not meet the target density. The densities (D) were ranged from 0.68-0.72 g/cm³. The low board densities were achieved by durian seed dextrin/citric acid 100/0 wt% (0.68 g/cm³) and maltodextrin/citric acid 100/0 wt% (0.69 g/cm³). This phenomenon might be resulted by the spring back of those boards which caused the thickness was > 1 cm. The high springback was occurred on those boards than other boards. It also indicated that the bonds among particles and dextrins were not so strong compared other boards using citric acid addition.

The MC values of the boards were ranged from 5.1-6.3%. All the MC values met the MC standard of JIS A 5908 (5-13%). The MC value was rather lowif it was compared to other bamboo particleboard that used citric acid-based adhesives (6.3-8%) (Widyorini et al., 2017), but almost same with the MC of Nipa particleboard with maltodextrin-based adhesives (±3- 8%) (Santoso et al., 2017).

The TS, WA and SR values of the boards were presented on Table 1. Only TS value of maltodextrin/citric acid (50/50) boards that could meet the TS value requirement of JIS A 5908 (max. 12%), meanwhile the boards with maltodextrin/citric acid (75/25 and 50/50) and durian seed dextrin/citric acid (50/50) had WA values that could meet the WA value standard of FAO (1966) (20-75%). The SR values in this research could not achieve the SR value of commercial particleboard (3.67-5.46 μm) (Hiziroglu & Suzuki, 2007), therefore it might not easy to cover the boards using veneer, vinyl or the other materials.

The TS, WA and SR values of durian seed dextrin/citric acid (100/0) particleboard was lower than maltodextrin/citric acid (100/0) particleboard. The TS value was 36% lower, while the WA and the SR value were 34% and 16% lower, respectively. This result indicated that durian seed dextrin particleboard has better water resistance-dimensional stability and surface smoothness than maltodextrin particleboard. Different results occurred when citric acid was added. The TS, WA and SR values of durian seed dextrin/citric acid was higher than maltodextrin/citric acid-based particleboard on each ratio of 75/25 and 50/50 wt%, except the SR values on ratio 75/25 wt%. It was expected that maltodextrin-citric acid has better compatibility on bamboo particles than durian seed dextrin-citric acid. Good compatibility could result on good bonding between adhesives and particles so the bonding is not easily broken by water. Sekino et al. (1999) stated that breakage of adhesives bond network was one of factors affecting in the TS values of resin bonded particleboard.

Table 1: The TS (thickness swelling), WA (water absorption), and SR (surface roughness) values of dextrin/citric acid-based particleboards.

	Maltodextrin/citric acid (wt%)		
	100/0	75/25	50/50
TS (%)	69.9 ± 5.2	19.8 ± 0.9	9.8 ± 0.2
WA (%)	192.0 ± 10.7	65.7 ± 5.2	42.4 ± 1.8
SR (μm)	15.44 ± 1.96	14.75 ± 1.34	10.63 ± 1.14
	Durian seed dextrin/citric acid (wt%)		
	100/0	75/25	50/50
TS (%)	44.6 ± 5.9	37.9 ± 4.2	14.1 ± 2.3
WA (%)	126.1 ± 13.7	99.9 ± 7.7	71.7 ± 2.0
SR (μm)	13.03 ± 1.78	13.31 ± 1.99	11.54 ± 1.72

Increasing citric acid ratio on the adhesive could bring positive trend on physical properties of particleboard. Increasing citric acid ratio could increase water resistance, dimensional stability and surface smoothness of the boards with dextrin based adhesive. This phenomenon also occurred on maltodextrin-based adhesives by Santoso et al. (2017) and sucrose-based adhesives by (Widyorini, Nugraha, et al., 2016). The carboxylic group of citric acid could undergo an esterification reaction when reacted with hydroxyl groups of lignocellulosic of bamboo to form ester linkages. This ester linkage could reduce free hydroxyl groups of lignocellulose that could bind with water so the physical properties of the boards, especially water resistance and dimensional stability increased (Umemura et al., 2011, 2012; Widyorini, Umemura, et al., 2016). The ester linkage could also increase the particles compactness and the board density so the surface smoothness was increased. Increasing the board density could decrease the surface roughness of particleboard (Nemli et al., 2005).

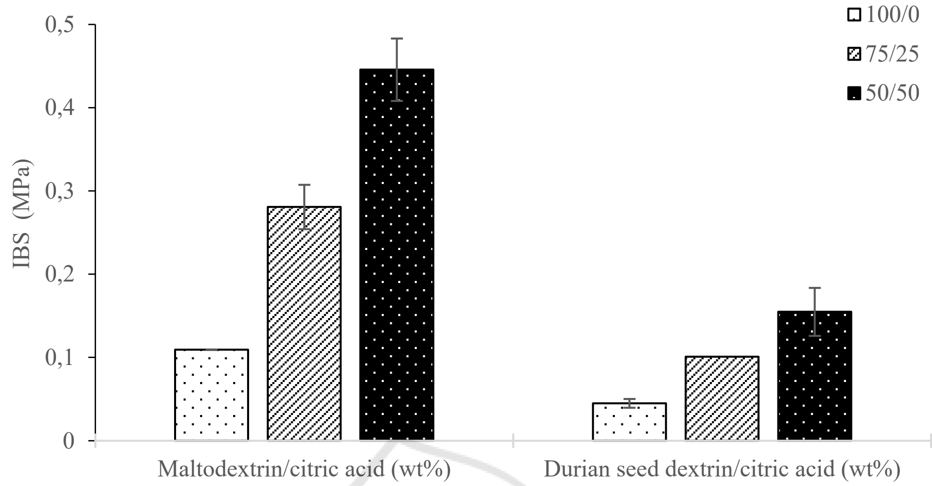

Figure 1: The internal bonding strength (IBS) values of dextrin-based particleboards.

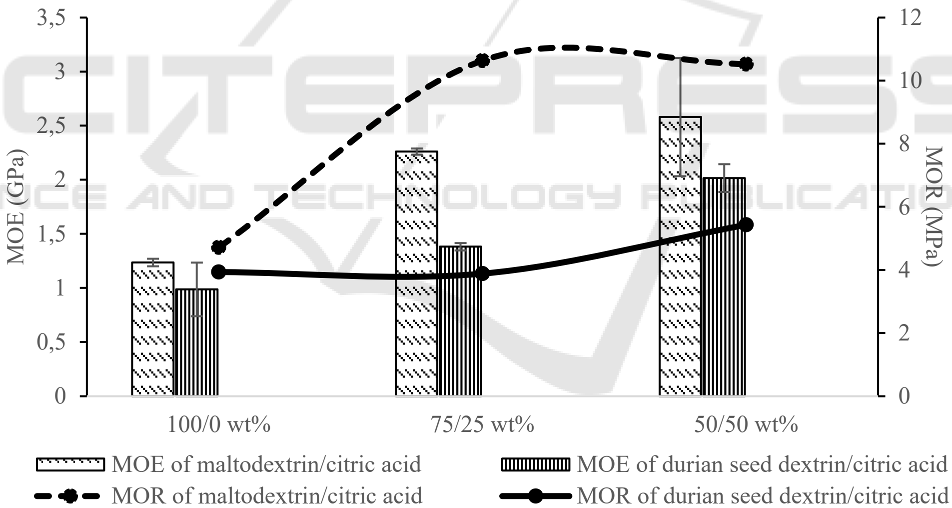

Figure 2: The modulus of rupture (MOR) and modulus elasticity (MOE) values of dextrin-based particleboards.

The IBS values of the dextrin-based particleboard could be seen in Figure 1. Maltodextrin-based particleboard has higher IBS value than durian seed dextrin-based particleboard on each mixture ratio. Good compatibility between maltodextrin/citric acid and lignocellulose from petung bamboo might be the reason behind those results. The IBS value of maltodextrin/citric acid (100/0) was higher 59% than durian seed dextrin/citric acid (100/0), although the both values could not meet JIS A 5908. The IBS value of durian seed dextrin/citric acid (75/25) was equivalent with the IBS value of maltodextrin/citric acid (100/0). The highest difference of IBS value between maltodextrin/citric acid and durian seed dextrin/citric acid was achieved at the ratio of 50/50. The IBS value of maltodextrin/citric acid could met the JIS A 5908 standard type 18 (min. 0.3 MPa). In addition, durian seed dextrin/citric acid-based particleboard has the IBS value that met the IBS value standard of JIS A 5908 type 8 (0.15 MPa) in the ratio of 50/50 wt%. Increasing the citric acid ratio into the dextrin adhesive could produce improvement trend of IBS as occurred on physical properties. Addition of 25% citric acid into maltodextrin (75/25) produces board with IBS value that 158% higher than IBS value of 100% maltodextrin (100/0). Ester linkage was expected to be able to increase bonding strength of inter-particles. This result showed that durian seed dextrin-based adhesive has lower bonding performance compared to maltodextrin-based adhesive. The future research on characterization of durian seed dextrin is needed to improve the bonding performance.

The MOR and MOE values were presented in Figure 2. The MOR and MOE were ranged from 3.9-10.6 MPa and 0.99-2.58 GPa, respectively. The MOE values with maltodextrin/citric acid adhesives (75/25 and 50/50) was 83% and 109% higher than MOE value with maltodextrin/citric acid (100/0) and both values met the MOE value standard of JIS A 5908 type 8 (min. 2 GPa). The MOE value of durian seed dextrin/citric cid(50/50) also met the standard. Only the MOR values of particleboard with maltodextrin/citric acid adhesives (75/25 and 50/50) that met the MOR value standard of JIS A 5908 type 8 (min. 8 MPa) and both value were 94-174% higher than other MOR values. The MOR and MOE values of particleboard with durian seed dextrin-based adhesive were lower than the MOR and MOE values of particleboard with maltodextrin-based adhesive at each ratio, but those values tend to be the same at100/0 wt% ratio. The biggest difference of the MOR and MOE values between both adhesives were occurred at dextrin/citric acid ratio of 75/25 wt% as the MOR and MOE values of maltodextrin/citric acid were 174% and 64% higher than MOR and MOE values of durian seed dextrin/citricacid, respectively.

4 CONCLUSIONS

Maltodextrin/citric acid based particleboards had higher physical and mechanical properties than durian seed dextrin/citric acid based particleboards, which it met the JIS A 5908 standard requirement. The best result in this research was the particleboard that used maltodextrin/citric acid (50/50) as adhesive. The further research is needed to investigate the difference between bonding mechanism of maltodextrin/citric acid based adhesive and durian seed dextrin/citric acid based adhesive. However, this research indicated that durian seed dextrin can be improved to be as natural adhesives.

ACKNOWLEDGEMENTS

Authors are grateful to Directorate of Higher Education (DIKTI), Ministry of Research, Technology and Higher Education of the Republic of Indonesia that had been funded this research via The Collaboration Research Program of Indonesia (PPKI 2019 scheme).

REFERENCES

BeMiller, J. N. (2003). Dextrin. In *Encyclopedia of Food Sciences and Nutrition 2nd edition* (pp. 1773–1775).

Castro-Cabado, M., Casado, A. L., & Román, J. S. (2016). Bio-based thermosets: Effect of the structure of polycarboxylic acids on the thermal crosslinking of maltodextrins. *European Polymer Journal*, *78*, 91–105. https://doi.org/https://doi.org/10.1016/j.eurpolymj.2016.03.007

Dokic, P., Jakovljevic, J., & Dokic-Baucal, L. J. (1998). Molecular characteristics of maltodextrins and rheological behaviour of diluted and concentrated solutions. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *141*(3), 435–440. https://doi.org/https://doi.org/10.1016/S0927-7757(97)00118-0

Hassid, W. Z. (1993). Dextrin. In *Encyclopedia of Science and Technology* (p. 172). McGraw-Hill, Inc.

Hiziroglu, S., & Suzuki, S. (2007). Evaluation of surface roughness of commercially manufactured particleboard and medium density fiberboard in Japan. *Journal of Materials Processing Technology*, *184*(1), 436–440.

Ho, L.-H., & Bhat, R. (2015). Exploring the potential nutraceutical values of durian (Durio zibethinus L.) – An exotic tropical fruit. *Food Chemistry*, *168*, 80–89. https://doi.org/https://doi.org/10.1016/j.foodchem.2014.07.020

JISA 5908. (2003). *JIS for Particleboards*. Japanese Industrial Standard.

Kennedy, H. M. (1989). *Starch-and dextrin-based adhesives*. ACS Publications.

Kollman, F. F. P., Kuenzi, E. W., & Stamm, A. J. (1975). *Priciples of wood science and technology II: wood based materials*. Spinger-Verlag.

Malini, D. R., Arief, I. I., & Nuraini, H. (2016). Utilization of durian seed flour as filler ingredient of meatball. *Media Peternakan*, *39*(3), 161–167.

Merck Index. (2006). Dextrin (Monograph No. 2953). In *The Merck index an encyclopedia of chemicals, drugs, and biologicals* (14th ed.). Merck & Co., Inc.

Nemli, G., Ozturk, I., & Aydin, I. (2005). Some of the parameters influencing surface roughness of particleboard. *Building and Environment*, *40*(10), 1337–1340. https://doi.org/http://doi.org/10.1016/j.buildenv.2004.12.008

Pimpa, W., Pimpa, C., & Junsangsree, P. (2012). Development of biodegradable films based on durian seed starch. *Advanced Materials Research*, *506*, 311–314. https://doi.org/https://doi.org/10.4028/www.scientific.net/AMR.506.311

Radley, J. A. (1976). *Industrial uses of starch and its derivatives*. Applied Sciece Publishers, Ltd.

Rowe, R. C., Sheskey, P. J., & Marian, E. Q. (2009). *Handbook of pharmaceutical excipients* (6th ed.). Parmaceutical Press.

Santoso, M., Widyorini, R., Prayitno, T. A., & Sulistyo, J. (2017). Bonding performance of maltodextrin and citric acid for particleboard made from nipa fronds. *Journal of the Korean Wood Science and Technology*, *45*(4), 423–443. https://doi.org/https://doi.org/10.5658/WOOD.2017.45.4.432

Sekino, N., Inoue, M., Irle, M., & Adcock, T. (1999). The mechanism behind the improved dimensional stability of particleboards made from steam-pretreatment particles. *Holzforschung*, *53*(3), 435–440. https://doi.org/https://doi.org/10.1515/HF.1999.072

Siriphanich, J. (2011). Durian (Durio zibethinus Merr.). In E. M. Yahia (Ed.), *Postharvest biology and technology of tropical and subtropical fruits, volume 3: cocona to mango* (pp. 80–116). Woodhead Publishing, Ltd.

Sugiarto, & Toana, N. M. (2018). The effect of durian (Durio zibethinus Murr) seed meal on nutritive value of the diet, performance and carcass percentage of broiler chickens. *Livestock Research for Rural Development*, *30*(8).

Umemura, K., Ueda, T., & Kawai, S. (2012). Effect of moulding temperature on the physical properties of wood-based moulding bonded with citric acid. *Forest Product Journal*, *62*(1), 63–68. https://doi.org/https://doi.org/10.13073/FPJ-D-11-00121.1

Umemura, K., Ueda, T., Munawar, S. S., & Kawai, S. (2011). Application of citric acid as natural adhesive for wood. *Journal of Applied Polymer Science*, *123*(4), 1991–1996. https://doi.org/https://doi.org/10.1002/app.34708

USDA. (2011). *Dextrin: handling/processing. Technical Evaluation Report*.

Widyorini, R., Nugraha, P. A., Rahman, M. Z. A., & Prayitno, T. A. (2016). Bonding ability of a new adhesive composed of citric acid-sucrose for particleboard. *BioResources*, *11*(2), 4526–4535. https://doi.org/https://doi.org/10.15376/biores.11.2.4526-4535

Widyorini, R., Umemura, K., Isnan, R., Putra, D. R., Awaludin, A., & Prayitno, T. A. (2016). Manufacture and properties of citric acid-bonded particleboard made from bamboo materials. *European Journal of Wood and Wood Products*, *74*(1), 57–65. https://doi.org/https://doi.org/10.1007/s00107-015-0967-0

Widyorini, R., Umemura, K., Septiano, A., Soraya, D. K., Dewi, G. K., & Nugroho, W. D. (2018). Manufacture and properties of citric acid-bonded composite board made from Salacca frond: effect of maltodextrin addition, pressing temperature, and pressing method. *BioResources*, *13*(4), 8662–8676. https://doi.org/https://doi.org/10.15376/biores.13.4.8662-8676