IMPROVED PERFORMANCE OF A MODIFIED YSD-UNIB SOLAR DRYER IN DRYING WASTE BRANCHES OF ACACIA MANGIUM WILLD. AND FALCATARIA MOLUCCANA (MIQ.) BARNEBY & J.W.GRIMES FOR CHARCOAL PRODUCTION

by Ridwan Yahya

FORESTRY IDEAS, 2022, vol. 28, No 1 (63): 205–214

IMPROVED PERFORMANCE OF A MODIFIED YSD-UNIB SOLAR DRYER IN DRYING WASTE BRANCHES OF *ACACIA MANGIUM* WILLD. AND *FALCATARIA MOLUCCANA* (MIQ.) BARNEBY & J.W.GRIMES FOR CHARCOAL PRODUCTION

Ridwan Yahya[1*], Udin Hasanuddin[2], Yuwana[3], Budiyanto[3], Yansen[1], Hery Suhartoyo[1], Lis W. Pasaribu[1], Cica K. Endang[1], and Andreas Sirait[1]

[1]Department of Forestry, Faculty of Agriculture, University of Bengkulu, Kota Bengkulu 38371.A, Indonesia. *E-mail: ridwanyahya@unib.ac.id

[2]Department of Agricultural Technology, Faculty of Agriculture, University of Bengkulu, Kota Bengkulu 38371.A, Indonesia.

[3]Department of Agricultural Technology, Faculty of Agriculture, University of Lampung, Jl. Sumantri Brojonegoro 1, Bandar Lampung 35145, Indonesia.

Received: 14 October 2021 Accepted: 06 June 2022

Abstract

Waste in the form of bark and wood from branches of *Acacia mangium* and *Falcataria moluccana* trees is abundant in forest plantations in Indonesia. It is challenging to use these branches due to their high water content. Open sun drying (OSD) takes a long time and the resulting moisture content of 10–15 % reached still leaves the wood susceptible to microorganism attack. The objectives of this study were 1) to compare the performance of a modified YSD-UNIB mixed-mode solar dryer (MSD) with that of an earlier model and 2) to compare moisture content and drying time of bark and wood chips of *A. mangium* and *F. moluccana* branches in OSD and the MSD. MSD was 10 °C hotter and 14 % drier than the original YSD-UNIB model. MSD reduced the moisture content of wood and bark samples of *A. mangium* (to 4.52 % and 5.40 %, respectively) and *F. moluccana* (to 3.81 % and 5.38 %, respectively), significantly more than OSD (10.41 % and 12.11 % for *A. mangium* wood and bark samples, respectively, and 10.42 % and 11.82 % for *F. moluccana* wood and bark samples, respectively). OSD also took longer (10 days) to dry samples of both species than did MSD (20 h for *A. mangium* and 12 h for *F. moluccana*). The regression equations fitted to the drying curves for *A. mangium* ($y = -8.746 \cdot \ln(x) + 32.49$) and *F. moluccana* ($y = -4.7 \cdot \ln(x) + 16.441$) wood chips in MSD, estimated that air-dry moisture content of 10.4 % was achieved in 12 h for *A. mangium* and only 5.43 h for *F. moluccana*. For chipped bark samples of both species, the regression equation $y = -8.322 \cdot \ln(x) + 31.874$ and $y = -4.57 \cdot \ln(x) + 18.517$, respectively, estimated that *A. mangium* also took longer (11.12 h) than *F. moluccana* (6.79 h) to reach air-dry moisture content (of 12.11 % and 11.82 %, respectively).

Key words: bark, branchwood, drying curves, mixed-mode solar dryer.

Introduction

Acacia mangium Willd. and *Falcataria moluccana* (Miq.) Barneby & J.W.Grimes are two fast-growing species recommended and widely planted in industrial forest plantation programs in Indonesia (Marbun et al. 2019, Rahmawati et al. 2019, Yahya et al. 2020a). Harvesting timber of fast-growing species such as both leaves a lot of unutilised branches on site (Alamsyah et al. 2020). While branch trimmings of several timber species have been used as firewood (Reina et al. 2016, Ben et al. 2017), bark is still underutilised resource and has a great potential for energy production (Wang et al. 2018). Bark comprises 2 % to 10 % of the stem (Sette et al. 2020). The smaller the size of the trunk or branch, the greater the percentage of bark.

Conversion of branch wood and bark waste to charcoal can increase its calorific value. One of the obstacles in using the waste as a raw material for charcoal is its high moisture content. The calorific value of a product is inversely related to the moisture content of the raw materials (Verma et al. 2017), including charcoal production.

Solar radiation is received in abundance by the earth. In the context of sustainable development, solar energy is efficient and effective. The use of conventional energy from fossil fuels and natural gas can be replaced by solar energy (Lingayat et al. 2020).

Generally, open sun drying (OSD) of biomaterials will only reach 10 % to 15 % air-dried moisture content and takes more than a week depending on on-site drying conditions. The attack of microorganisms occurs on biomaterials with a moisture content greater than 10 % (Sulaiman et al. 2013). Technically, the best method to achieve quick drying to a targeted moisture content is by using a kiln dryer, which controls temperature, humidity and air flow. The drawback is the relatively expensive price of the equipment. Therefore, it is necessary to look for other drying alternatives.

The University of Bengkulu in the last decade developed a mixed-mode solar dryer called YSD-UNIB. It consists of a drying chamber, two heat collectors, a chimney equipped with an air outlet and inlet and a pair of doors. The dryer has successfully dried red pepper, mustard greens and cassava leaves (Yuwana and Silvia 2012), cassava (Silvia and Yuwana 2012) and catfish (Yuwana et al. 2017).

To improve its performance, the rectangular chimney running lengthwise to the dryer was replaced with a square, centered chimney, producing a modified YSD-UNIB solar dryer (hereafter referred to as MSD). The consequently smaller chimney (Fig. 1) was designed to concentrate the hot air in the chimney into a smaller space so that the hot air would be better distributed throughout the drying rack. Initial measurements show that chimney reached temperatures of up to 80 °C.

Solar-based drying for agro-products is quicker than wood (Simo-Tagne et al. 2020) because agricultural products are generally thinner and smaller. Because the waste size is relatively small, one of the recommended product sizes for energy production is in the form of chips (Moskalik and Gendek 2019). The thickness of the wood is directly proportional to the energy required for drying (Bentayeb et al. 2008). In our study, the bark and wood from waste branches were dried and subsequently used to produce charcoal (reported separately).

The novelty of this work is anticipated that MSD will dry the bark and wood chips

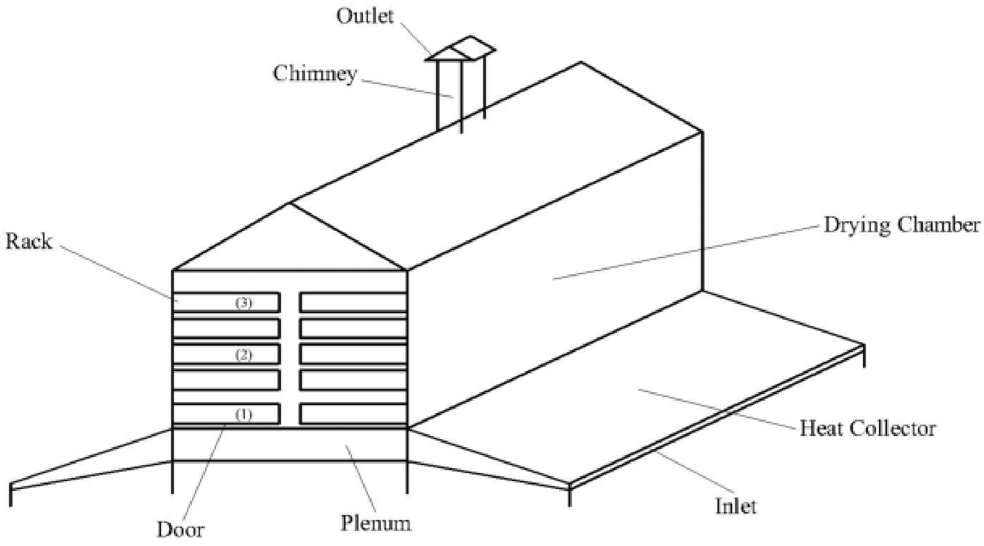

Fig. 1. Schematic diagram of modified YSD-UNIB solar dryer.

from branches more quickly than OSD. MSD is also expected to reach a higher temperature and lower humidity than other mixed-mode solar dryers, in which case it could be recommended for drying green wood for producing charcoal. Because the levels of chemical components that make up wood and bark from *A. mangium* and *F. moluccana* are different (Nawawi et al. 2018), and differing levels of chemical components in wood and bark may affect the quality of the resulting product (Park et al. 2017, Yahya et al. 2017), our study also aims at to compare moisture contents of the bark and wood of *A. mangium* and *F. moluccana* branches.

Material and Methods

Sample preparation

A 3–8 cm diameter branch was taken from each of twenty *A. mangium* and *F. moluccana* trees that had been randomly selected from a forest plantation in Bengkulu, Indonesia. Branches were immediately placed into polyethylene bags and brought to the laboratory. They were debarked and chips measuring 25×21×3 mm (length × width × thickness) were cut from the debarked branch and the bark itself. The thickness of bark chips varied according to bark thickness, which was in the range of 2.5–3.5 mm.

Drying methods

The bark and wood chips were dried in two ways namely OSD and MSD (Fig. 1). The working mechanism of the mixed-mode solar dryer including MSD is as follows. As long as sun rays strike the structure of the dryer, the drying chamber accumulates solar energy directly from the sun rays passing through its roof and the wall while the heat collector gathers solar energy from the sun rays passing through its roof and striking the upper surface plate. Solar energy obtained in the drying chamber increases the drying air while the absorbed energy by the surface plate escalates its temperature and uses it to heat the entering fresh air from the inlet and the heated air flows into the drying chamber and further increases the drying air in it. Due to the enclosed system of drying air in the structure of the dryer, there is a pressure gradient between a point in the lower end of heat collector and a point in the upper end of chimney, then creates a continues flow of the drying air from the inlet passing through the trays to the outlet. The passing drying air heats the samples on the trays and evaporates its moisture content, and its content decreases during the drying process (Yuwana et al. 2017).

Samples of chips weighing 150 g per replicate were spread out on paper trays measuring 23×15 cm, with 20 replicates per treatment for a total of 80 samples. Samples were arranged in a nested design under the sun and in the drying chamber of solar dryer and were left to dry from 8 a.m. to 4 p.m. daily until a constant weight was reached (Montgomery 2013). Samples in the solar dyer were weighed every 4 h during the drying period but if rain was forecast, samples were weighed every 2 h. OSD samples were weighed once at the end of the day's drying period, i.e. at 4 p.m. daily. Drying the chips with OSD and MSD was carried out until the chips gained a constant weight. Temperature and humidity were recorded outside and inside the solar dryer throughout the experiment.

Five chips from each replicate sample that had reached constant weight with OSD and the solar dryer were measured their weight (IW), and further oven-dried to constant weight (ODW) to determine final sun- and solar dryer-dried moisture content (*MC*). *MC* was calculated according to the formula (1):

$$MC = \frac{IW - ODW}{IW} \cdot 100 \text{ , \%} \qquad (1)$$

Volume of the oven-dried chips was measured using the water displacement method (Fan et al. 2012). The oven-dried density was determined as weight of the oven-dried chips divided by its volume.

An ANOVA of nested design, with species as the whole plots and branch components as subplots, was used to determine effect of species, branch component, moisture content level, and their interactions, on moisture content. Fisher Least Significant Difference (LSD) Method was used to compare treatment means at the 5 % significance level. The relationships between drying time and moisture content of wood and bark chips dried in the solar dryer were calculated using simple regression. The regression equations were used to predict the drying time needed by wood and bark chips to reach final air-dried (constant-weight) moisture content.

Results and Discussion

Moisture content of branch components in relation to tree species

The moisture content of bark and wood samples from MSD was significantly lower than that from OSD and of green wood (Table 1).

Table 1. Effect of interaction between branch component and moisture content level by ANOVA.

Interaction between branch componentand moisture content level	Average moisture content, %
Bark, wet basis (initial)	55.11a
Wood, wet basis (initial)	40.25b
Bark, air dry OSD	11.97c
Wood, air dry OSD	10.41c
Wood, dried in MSD	5.39d
Bark, dried in MSD	4.16d

Note: *Post hoc* Fisher's LSD significant differences at the 0.05 level are indicated with different letters.

Taken freshly harvested branches (wet basis), the moisture content of bark was significantly higher than that of wood (Table 1). The higher levels of extractives in the bark as compared with the wood may explain the differences in their initial moisture content. Nawawi et al. (2018) reported that hot water solubility of *A. mangium* wood and bark was 7.31 % and 16.41 % respectively, sodium hydroxide solubility was 20.60 % and 42.24 % respectively, and ethanol-benzene solubility was 8.01 % and 14.92 %, respectively; while for *F. moluccana* wood and bark, hot water solubility was 5.75 % and 12.68 % respectively, sodium hydroxide solubility was 17.26 % and 32.43 %, respectively, and ethanol-benzene solubility was 5.83 % and 8.01 %, respectively. The deposition of extractive substances in the pit prevents the release of water from the biomaterial in the drying process (Jankowska et al. 2017).

Comparing the two drying methods

MSD reduced the moisture content of the wood and bark chip samples of both *A. mangium* and *F. moluccana*, which was significantly lower than that of OSD (Table 2). OSD also took longer time (10 days) to dry the samples of *A. mangium* and *F. moluccana* to final constant moisture content than did MSD (20 h and 12 h, respectively). This result could be attributed to the very hot and dry conditions within MSD drying chamber. Mean temperature and humidity in the drying chamber were 52.8 ±1.5 °C and 21 ±4.4 % respectively, while 32.1 ±1.6 °C and 69.5 ±5.6 % respectively, outside.

With the modified smaller, centered chimney, MSD was also hotter and drier than the original YSD-UNIB solar dryer. The latter drying chamber reached mean temperature and humidity values of 43 ±2.8 °C and 35.3 ±2.7 % respectively, while it was 33.3 ±1.5 °C and 58.8 ±2.9 % outside (Yuwana et al. 2017). Reducing the chimney size appears to have increased MSD drying chamber temperature by 10 °C and reduced the humidity by 14 % compared with the original YSD-UNIB solar dryer.

MSD also performed better than other mixed-mode solar dryers. Ugwu et al.

Table 2. Moisture content and drying time of chipped branch components dried under OSD and MSD.

Branch component	Drying method	Moisture content, %			Drying time
		Initial (wet)	At constant (dry) weight	Difference	
A. mangium					
Wood	OSD	41.73	10.41	31.32	10 days
	MSD	41.73	4.52**	37.21	20 h
Bark	OSD	51.70	12.11	39.59	10 days
	MSD	51.70	5.40**	46.30	20 h
F. moluccana					
Wood	OSD	38.77	10.42	28.35	10 days
	MSD	38.77	3.81**	34.96	12 h
Bark	OSD	58.52	11.82	46.70	10 days
	MSD	58.52	5.38**	53.14	12 h

Note: ** – significantly different at the 0.01 level.

(2015) reported temperature and humidity values of 44–50 °C and 32–35 % respectively for their wood-drying solar dryer. Sulaiman et al. (2013) reported that the temperature in their mixed-mode dryer reached 35.86–45.22 °C. Efficient drying is driven by high temperature and low humidity in the dryer (Lingayat et al. 2020) and our results for MSD indicate good potential for efficiently removing moisture in green wood chips in the process of carbonisation (Verma et al. 2017). The heating value is inversely proportional to the moisture content of a material (Mohammed et al. 2019) thus the well-dried chips from MSD are suitable for producing charcoal with good burning quality. Additionally, the dried chips are resistant to attack by microorganisms, which need moisture levels above 10 % to actively deteriorate biomaterial (Sulaiman et al. 2013).

MSD can reduce the cost of transporting of these raw materials to charcoal-producing facilities. These transportation costs need to be considered particularly for *A. mangium* and *F. moluccana* because the charcoal kilns are typically far from forest plantations (Yahya et al. 2020b). Drying branch logs using MSD before transportation could reduce overall production costs. The energy required to dry wood in the wood processing industry can reach 70 % of the total production cost (Blanche et al. 2016) thus solar drying is beneficial because it reduces weight, transportation costs and packaging problems, and improves product stability (Chandramohan 2016, Bekkioui et al. 2020). Another advantage of using MSD is that the solar collector can reduce CO_2 emissions. The solar collector of an indirect hybrid solar dryer in Morocco helped to reduce annual CO_2 emissions by 34 % (Lamrani et al. 2019).

An alternative way to help reduce transportation costs could be siting the charcoal kiln with MSD to directly produce charcoal after drying the chips. The resulting charcoal will have a low moisture content that is relatively constant and stable because charcoal is hydrophobic (Leal et al. 2019) thus minimising transportation costs.

Predicted drying times of wood and bark chips in the solar dryer

It was predicted that *A. mangium* wood (equation $y = -8.746 \cdot \ln(x) + 32.49$, Fig. 2a) would require longer (12 h) to reach the air dry moisture content (10.41 %), whereas *F. moluccana* wood was predicted (equation $y = -4.7 \cdot \ln(x) + 16.441$, Fig.2b) to require only 5.43 h to reach air dry moisture content (10.42 %). Bark from the branches of the two species also required different drying times. Using the equations for the bark in figures 2c and 2d, *A. mangium* bark samples were predicted to take 11.12 h to reach the air dry moisture content (12.11 %) with OSD, while *F. moluccana* bark would only take 6.79 h to reach air dry moisture content (11.82 %) with OSD.

Extractive content and cell wall thickness is thought to influence drying time. The extractive content of bark and wood of *A. mangium* was higher than that of bark and wood of *F. moluccana*, respectively (Nawawi et al. 2018). The longer drying time for bark and the added production cost of debarking are factors that need to be considered when including bark in producing energy from *A. mangium* and *F. moluccana* branches.

Results of present study showed that the density of *A. mangium* wood (0.48 ±0.05 g·cm^{-3}) was significantly greater ($p < 0.05$) than the density of *F. moluccana* wood (0.36 ±0.03 g·cm^{-3}, Table 3). For *A. mangium* and *F. moluccana* density of the

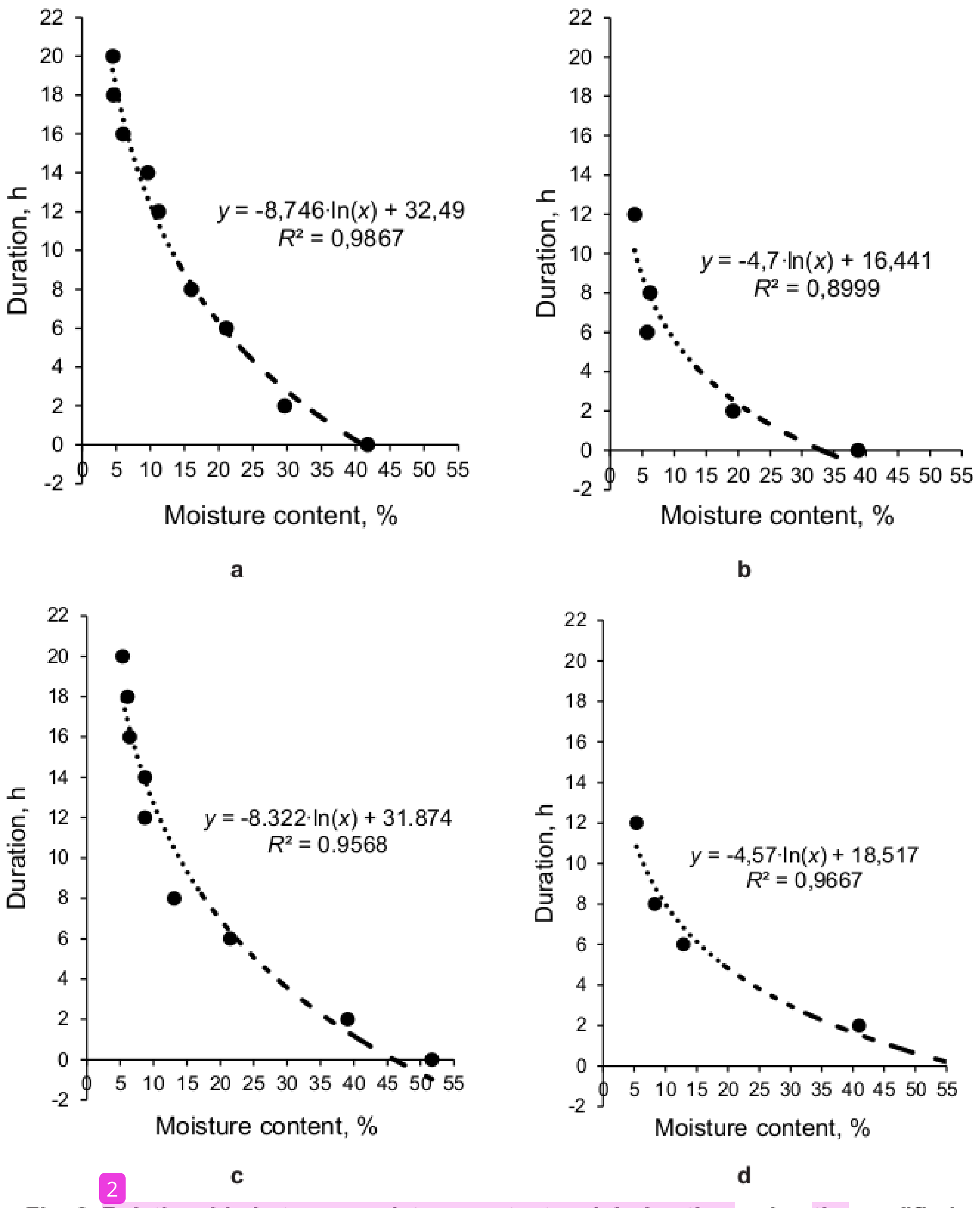

Fig. 2. Relationship between moisture content and drying time using the modified YSD-UNIB solar dryer for wood of: a) *A. mangium*; (b) *F. moluccana* and bark of (c) *A. mangium*; (d) *F. moluccana* branches.

bark is also higher than that of the wood. The density of wood is directly proportional to the cell wall thickness (Werdin et al. 2020). The thickness of the cell wall is directly proportional to the amount of bound water in the wood, and the bound water takes a longer time than free water in the drying process (Penvern et al. 2020).

Table 3. Density of wood and bark of *A. mangium* and *F. moluccana* branches.

No	Variables	Density, $g \cdot cm^{-3}$
1	Branchwood of *A. mangium*	0.48*
	Branchwood of *F. moluccana*	0.36
2	Bark of *A. mangium* branches	0.62ns
	Bark of *F. moluccana* branches	0.61
3	Branchwood of *A. mangium*	0.48
	Bark of *A. mangium* branches	0.62*
4	Branchwood of *F. moluccana*	0.36
	Bark of *F. moluccana* branches	0.61**

Note: ** – significantly different at the 0.01 level, * – at the 0.05 level, ns – no significantly different.

Conclusions

MSD was 10 °C hotter and 14 % drier than the original YSD-UNIB model. Its ability to dry wood chips to 10 % moisture content in 12 h and 5.43 h for *A. mangium* and *F. moluccana* wood respectively, while OSD took 10 days demonstrates its potential in pre-processing waste *A. mangium* and *F. moluccana* branches for subsequent charcoal production.

Acknowledgments

This study was financially supported by the University of Bengkulu, Indonesia, through a national collaborative research schema with the contract number 2062/UN30.15/PG/2020.

References

Alamsyah E.M., Sutrisno., Sumardi I, Darwis A., Suhaya Y., Hidayat Y. 2020. The possible use of surian tree (*Toona sinensis* Roem) branches as an alternative raw material in the production of composite boards. Journal of Wood Science 66: 1–6. https://doi.org/10.1186/s10086-020-01871-6

Bekkioui N., El Hakiki S., Rachadi A., Ez-Zahraouy H. 2020. One-year simulation of a solar wood dryer with glazed walls in a Moroccan climate. Renewable Energy 155: 770–782. https://doi.org/10.1016/j.renene.2020.03.131

Ben H., Hao N., Liu Q., Ragauskas A.J. 2017. Solid-state NMR investigation of bio-chars produced from biomass components and whole biomasses. BioEnergy Research 10: 1036–1044. https://doi.org/10.1007/s12155-017-9863-2

Bentayeb F., Bekkioui N., Zeghmati B. 2008. Modelling and simulation of a wood solar dryer in a Moroccan climate. Renewable Energy 33: 501–506. https://doi.org/10.1016/j.renene.2007.03.030

Blanche P., Kaboorani A., Bustos C. 2016. Understanding effects of drying methods on wood mechanical properties at ultra and cellular levels. Wood and Fiber Science 48: 117–128.

Chandramohan V.P. 2016. Numerical prediction and analysis of surface transfer coefficients on moist object during heat and mass transfer application. Heat Transfer Engineering 37: 53–63. https://doi.org/10.1080/01457632.2015.1042341

Fan Z.X., Zhang S.B., Hao G.Y., Slik J.W.F., Cao K.F. 2012. Hydraulic conductivity traits predict growth rates and adult stature of 40 Asian tropical tree species better than wood density. Journal of Ecology 100(3): 732–741. https://doi.org/10.1111/j.1365-2745.2011.01939.x

Jankowska A., Drożdżek M., Sarnowski P., Horodeński J. 2017. Effect of extractives on the equilibrium moisture content and shrinkage of selected tropical wood species. BioResources 12(1): 597–607. https://doi.org/10.15376/biores.12.1.597-607

Lamrani B., Khouya A., Draoui A. 2019. Energy and environmental analysis of an indirect hybrid solar dryer of wood using TRNSYS software. Solar Energy 183:

132–145. https://doi.org/10.1016/j.solener.2019.03.014

Leal O.d.A., Dick D.P., de La Rosa J.M., Leal D.P.B., González-Pérez J.A., Campos G.S., Knicker H. 2019. Charcoal fine residues effects on soil organic matter humic substances, composition, and biodegradability. Agronomy 9: 1–16. https://doi.org/10.3390/agronomy9070384

Lingayat A.B., Chandramohan V.P., Raju V.R.K., Meda V. 2020. A review on indirect type solar dryers for agricultural crops – dryer setup, its performance, energy storage and important highlights. Applied Energy 258: 1–22. https://doi.org/10.1016/j.apenergy.2019.114005

Marbun S.D., Wahyudi I., Suryana J., Nawawi D.S. 2019. Anatomical structures and fiber quality of four lesser-used wood species grown in Indonesia. Journal of the Korean Wood Science and Technology 47(5): 617–632. https://doi.org/10.5658/WOOD.2019.47.5.617

Mohammed M., Ozbay I., Karademir A., Donkor A. 2019. Effect of waste matrix for the optimization of moisture content and calorific value of biodried material using Taguchi DOE. Drying Technology 37: 1352–1362. https://doi.org/10.1080/07373937.2018.1500484

Montgomery D.C. 2013. Design and Analysis of Experiments. Eighth edition. John Wiley & Sons Inc., Hoboken, NJ, USA. 752 p.

Moskalik T., Gendek A. 2019. Production of chips from logging residues and their quality for energy: a review of European literature. Forests 10: 1–14. https://doi.org/10.3390/f10030262

Nawawi D.S., Carolina A., Saskia T., Darmawan D., Gusvina S.L., Wistara N.J., Sari R.K., Syafii W. 2018. Karakteristik kimia biomassa untuk energi (Chemical characteristics of biomass for energy). Ilmu Teknologi Kayu Tropis 16(1): 45–51 (in Indonesian).

Park S.Y., Kim., J.C., Kim., J.H., Yang., S.Y., Kwon O., Yeo H., Cho K.C., Choi I.G. 2017. Possibility of wood classification in Korean softwood species using near-infrared spectroscopy based on their chemical compositions. Journal of the Korean Wood Science and Technology 45(2): 202–212.

Penvern H., Zhou M., Maillet B., Courtier-Murias D., Scheel M., Perrin J., Weitkamp T., Bardet S., Caré S., Coussot P. 2020. How bound water regulates wood drying. Physical Review Applied 14(5): 1–20. https://doi.org/10.1103/PhysRevApplied.14.054051

Rahmawati D., Khumaida N., Siregar U.J. 2019. Morphological and phytochemical characterization of susceptible and resistant sengon (*Falcataria moluccana*) tree to gall rust disease. Biodiversitas 20(3): 907–913. https://doi.org/10.13057/biodiv/d200340

Reina L., Botto E., Mantero C., Moyna P., Menéndez P. 2016. Production of second generation ethanol using *Eucalyptus dunnii* bark residues and ionic liquid pretreatment. Biomass and Bioenergy 93: 116–121. https://doi.org/10.1016/j.biombioe.2016.06.023

Sette C.R.Jr, da Cunha T.Q.G., Coneglian A., Hansted A.L.S., da Silva D.A., Lima P.A.F., da Silva M.F., Yamaji F.M. 2020. Does the presence of bark in the wood of fast-growing forest species significantly change the energy potential? Bioenergy Research 13: 222–228. https://doi.org/10.1007/s12155-020-10115-w

Silvia E., Yuwana Y. 2012. Performance of the YSD-UNIB12 solar dryer for cassava drying. In Marwanto., Prasetyo., Widiono S (Eds), Proceeding of National Seminar entitled Toward Agriculture Souverignity. Faculty Agriculture Publishing: 263–270 (in Indonesian).

Simo-Tagne M., Ndukwu M.C., Azese M.N. 2020. Experimental modelling of a solar dryer for wood fuel in Epinal (France). Modelling–International Open Access Journal of Modelling in Engineering Science 1: 39–52. https://doi.org/10.3390/modelling1010003

Sulaiman F., Abdullah N., Aliasak Z. 2013. Solar drying system for drying empty fruit bunches. Journal of Physical Science 24: 75–93.

Ugwu S.N., Ugwuishiwu B.O., Ekechukwu O.V., Njoku H., Ani A.O. 2015. Design, construction, and evaluation of a mixed mode solar kiln with black-painted pebble bed for timber seasoning in a tropical setting. Renewable and Sustainable Energy Reviews 41: 1404–1412. https://doi.org/10.1016/j.

rser.2014.09.033

Verma M., Loha C., Sinha A.N., Chatterjee P.K. 2017. Drying of biomass for utilising in co-firing with coal and its impact on environment – a review. Renewable and Sustainable Energy Reviews 71: 732–741. https://doi.org/10.1016/j.rser.2016.12.101

Wang L., Barta-Rajnai E., Skreiberg Ø., Khalil R., Czégény Z., Jakab E., Barta Z., Grønli M. 2018. Effect of torrefaction on physiochemical characteristics and grindability of stem wood, stump and bark. Applied Energy 227: 137–148. https://doi.org/10.1016/j.apenergy.2017.07.024

Werdin J., Fletcher T.D., Rayner J.P., Williams N.S.G., Farrell C. 2020. Biochar made from low density wood has greater plant available water than biochar made from high density wood. Science of the Total Environment 705: 1–22. https://doi.org/10.1016/j.scitotenv.2019.135856

Yahya R., Yansen Y., Sundaryono A., Horikawa Y., Sugiyama J. 2017. Neighborhood of vessels: chemical composition and microfibril angle of fiber within *Acacia mangium*. Journal of Tropical Forest Science 29: 267–274. https://doi.org/10.26525/jtfs2017.29.3.267274

Yahya R., Yansen Y., Tazuru-Mizuno S. 2020a. Fibre quality: length and slenderness ratio of fibre adjacent to small vessels of *Acacia mangium*. Journal of Tropical Forest Science 32: 355–360. https://doi.org/10.26525/jtfs2020.32.4.355

Yahya R., Yansen Y., Tazuru-Mizuno S., Sugiyama J. 2020b. Effect of vessel diameter on variation of fiber morphology in *Acacia mangium*. IAWA Journal 41: 2–11. https://doi.org/10.1163/22941932-00002100

Yuwana Y., Silvia E. 2012. Utilization of YSD-UNIB12 solar dryer for red pepper, mustard greens, cassava leaf drying. In Marwanto., Prasetyo., Widiono S. (Eds), Proceeding of National Seminar entitled Toward Agriculture Souverignity. Faculty Agriculture Publishing: 145–153 (in Indonesian).

Yuwana Y., Tarigan R.N.B., Silvia E. 2017. Solar drying modes of catfish (*Clarias gariepinus*). International Journal of Engineering Inventions 6: 6–12.

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