Food Research 8 (Suppl. 1) : 29 - 35 (2024)
Journal homepage: https://www.myfoodresearch.com

FOOD RESEARCH

RESEARCH PAPER

Gadung tuber pasta drying: kinetic model development and physical quality evaluation

[1]Utari, F.D., [2]Siqhny, Z.D., [1]Prasetyaningrum, A. and [1,*]Djaeni, M.

[1]*Department of Chemical Engineering, Faculty of Engineering, Diponegoro University. Semarang, Indonesia*
[2]*Faculty of Agriculture Technology, Semarang University, Semarang, Indonesia*

Article history:
Received: 7 March 2023
Received in revised form: 31 October 2023
Accepted: 8 December 2023
Available Online: 3 March 2024

Keywords:
Drying,
Gadung tuber,
Kinetics,
Pasta

DOI:
https://doi.org/10.26656/fr.2017.8(S1).5

Abstract

Gadung tuber (*Dioscorea hispida* dennst.) is a carbohydrate-rich food source that is easily found in Indonesia. Studies have been carried out on pretreatment methods to reduce anti-nutritional compounds in gadung tubers. So gadung tubers can be promoted as the raw materials of several food products such as pasta. Drying is the most crucial process that will determine the final quality of the pasta product. This study aimed to investigate the kinetic models of gadung tuber pasta drying and its physical quality. Four thin-layer models (Newton, Page, Handerson-Pabis and Logarithmic) were employed to find the selected model. The gadung tuber pasta was formulated using low, medium, and high protein wheat flour and then was dried at a temperature of 30-70°C. The moisture content was observed every 30 mins for 240 mins. The result showed that the moisture reduction was higher in higher drying temperatures and lower protein wheat flour. The Logarithmic model was selected to predict the drying kinetics of gadung tuber pasta drying with the highest value of R^2 and the lowest value of RMSD. The cyanide content in gadung tuber pasta meets the standard, indicating that the gadung tubers pasta may safety to consume.

1. Introduction

Pasta products have been around for thousands of years and play an important role in human nutrition and culture. Pasta is usually made from a mixture of wheat flour and then formed by extrusion (Wrigley *et al*., 2004). Pasta production in Indonesia is influenced by the availability of wheat flour. Wheat flour in Indonesia is an imported commodity and the demand of wheat flour in Indonesia is always increasing every year (Soesilowati *et al.*, 2019). It is important to create a food product that can meet the criteria as an alternative food rich in energy and nutrition based on local ingredients to diversify food and at the same time reduce dependence on imports.

Gadung tuber (*Dioscorea hispida* dennst) is a carbohydrate-rich food source that is easily found in tropic regions. About 20 g of carbohydrates are found in every 100 grams of gadung tubers (Kumoro *et al*., 2012). Additionally, gadung tubers contain antinutritional substances such as dioscorin, histamine, saponins and hydrogen cyanide (HCN) (Widiyanti and Kumoro, 2017). The presence of these toxic compounds in gadung tuber such as cyanide and dioscorin leads to the serious health complications, making the application of gadung tubers limited. A recent study has been conducted to find the pretreatment process to reduce the antinutritional substances in gadung tubers (Kumoro and Hartati, 2015).

Fresh pasta does not last long because it has a high water content. While dry pasta can be stored for up to 3 years or more because it only has a water content of 10%. To produce dry pasta that has a long shelf life, a drying process is needed. Drying is the process of reducing or eliminating the moisture content of a material with the help of heat (Tavakolipour and Mokhtarian, 2015). The drying process involves simultaneous heat and mass transfer in a multiphase system which aims to extend the shelf life of a material (Arora *et al*., 2006; Mihindukulasuriya and Jayasuriya, 2013). In addition to increasing the shelf life, drying also aims to facilitate distribution because the mass of the material will be reduced, reduce packaging and reduce transportation costs (Kamalakar *et al*., 2014).

Based on the literature study, the application of gadung tubers is only for flour and chips (Kumoro *et al*., 2012; Nugroho and Estyaniyana, 2018). Since the pretreatment can reduce the antinutritional substances, the combination of wheat flour and gadung tubers flour can be an option as the raw materials of pasta. Drying is

*Corresponding author.
Email: *moh.djaeni@live.undip.ac.id*

eISSN: 2550-2166 / © 2023 The Authors.
Published by Rynnye Lyan Resources

the most crucial process that will determine the final quality of the pasta product. The drying kinetics and moisture content of the final product are very important in the drying process (Mujumdar, 2006). In addition, other factors affect the success of drying, among others, surface area, differences in temperature and the surrounding air, air flow velocity and air pressure. The kinetic models can be used to estimate the drying kinetics constant and predict the drying time. The purpose of this study was to investigate the kinetic models of gadung tuber pasta and its physical quality. To date, studies on the kinetic models of gadung tubers pasta drying have not been well studied.

2. Materials and methods

2.1 Materials

Postharvest of gadung tuber was obtained from a local farmer in Rowosari, Semarang, Indonesia. The commercial wheat flour was purchased from Bogasari Flour Mills Ltd. (Jakarta, Indonesia). This flour contained low, medium, and high protein (about 10-14%). Sodium bicarbonate ($NaHCO_3$) solution was used to reduce cyanide levels in gadung tubers and was purchased from Sigma. CMC was added to the pasta formulation.

2.2 Preparation of gadung tuber pasta

The cyanide content in postharvest gadung tuber was reduced by chemical treatment using sodium bicarbonate (Latif *et al*., 2019). The concentration of cyanide was determined by the picrate paper method (Odoemelam *et al*., 2020). Then the gadung tubers were drained and dried in a food dehydrator (ARD-PM99, Maksindo, Indonesia). The dried gadung tubers were milled and sieves into 80 mesh. The ratio of wheat flour and gadung tuber flour was 9:1. The addition of CMC was about 1% of the total weight. The formulation was done with the variation of protein content in wheat flour: low (10% of protein), medium (11.5% of protein) and high (14% of protein). About 75 ml of water was added to the formulation. Then the dough was mixed and stirred. The prepared dough was added to the pasta extruder (Multi Maker OX-123, Oxone, Indonesia) for the pasta casting.

2.3 Gadung tuber pasta drying

The drying process was conducted at different drying temperatures (30, 50 and 70°C). The gadung tuber pasta was placed on the tray (length of 10 cm, width of 7 cm and thickness of 0.2 cm). The sample was then put in a food dehydrator and weighed every 30 mins for 240 mins to observe the moisture content reduction.

2.4 Thin layer model

The moisture content during the drying time can be converted into dimensionless moisture, namely moisture ratio (MR), which can be seen in Equation 1.

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

Where M_t was the moisture content at a certain time (t), M_0 was initial the moisture content (at t = 0), and M_e was the equilibrium moisture content. The M_t, M_0 ,M_e and was expressed on a dry basis. Equation 1 was then simplified into Equation 2 because the value of was relatively small (Azizpour *et al*., 2013).

$$MR = \frac{M_t}{M_0} \quad (2)$$

The thin layer model that was used to describe the drying phenomenon of gadung tuber pasta were listed in Table 1. The suitable model was selected based on the statistical parameter: a higher value of the coefficient of determination (R^2) and a lower value of Root Mean Square Deviation (RSMD). The statistical parameter was evaluated using POLYMATH Educational 6.0 software.

3. Results and discussion

3.1 Cyanide determination

In the gadung pasta production process, HCN levels are reduced to maintain food safety. The process of reducing HCN is carried out by immersion in a sodium bicarbonate solution. After the immersion process, HCN levels were tested to determine the toxicity of flour. There was a reduction in HCN levels from 62.33±0.26 ppm to 23.89±0.49 ppm (Figure 1). Gadung tuber pasta showed the lowest cyanide concentration at 9.47±0.14 ppm. The food processing in this study including the drying process reduced the level of cyanide by 62%.

Based on these standards, the product, gadung tuber

Table 1. Thin-layer models for gadung tuber pasta drying.

Model	Equation		References
Newton	$\boldsymbol{MR = \exp(-kt)}$	(3)	Ertekin and Firat (2017)
Page	$\boldsymbol{MR = \exp(-kt^n)}$	(4)	Aregbesola *et al.* (2015)
Henderson and Pabis	$\boldsymbol{MR = a \cdot \exp(-kt)}$	(5)	Jian and Jayas (2018)
Logarithmic	$\boldsymbol{MR = a \cdot \exp(-kt) + b}$	(6)	Yogendrasasidhar and Setty (2019)

Where k was the drying constant (min^{-1}) and n, a, and b were the dimensionless model constants.

https://doi.org/10.26656/fr.2017.8(S1).5

pasta meets the standards for HCN levels in food. The standard limit for HCN in food based on the World Health Organisation (WHO) is 10 ppm (Odoemelam *et al.,* 2020). This indicated that the gadung tubers pasta may safe to consume. Several food products also showed a reduction of cyanide after food processing: cake and cookies from yellow root cassava contain 7-10 ppm of cyanide (Odoemelam *et al*., 2020) and cassava flour contains 6.61 ppm of cyanide (Bandna Address and Chand, 2012).

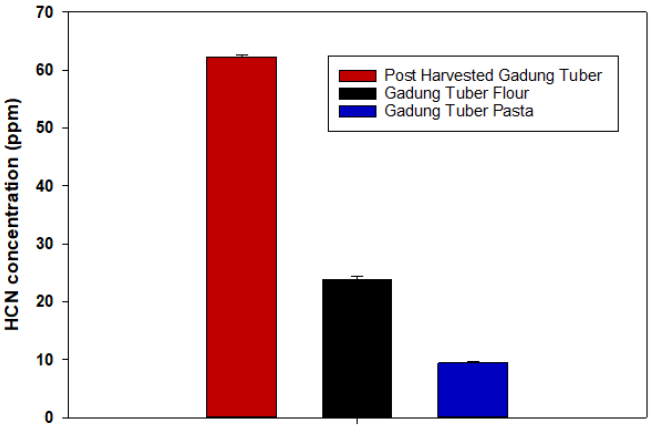

Figure 1. HCN concentration in post-harvested gadung tuber and products.

3.2 Gadung tuber pasta morphology

The morphology of gadung tuber pasta is shown in Figure 2. Figure 2A-2C displayed the morphological surface of gadung tuber pasta with high, medium and low protein wheat flour. The cross-sectional image of gadung tuber pasta with high, medium, and low protein wheat flour can be seen in Figure 2D-2F. In Figure 2A-2C the gadung tuber pasta exhibits a smooth and compact surface. While in the cross-sectional image, the gadung tuber pasta with medium and low protein wheat flour (Figure 2E-2F possesses some pores or holes, which may be attributed to the bonds with the water molecules. In the drying process of the pasta with the lower protein wheat flour, hydrogen bonds become lower, resulting in some pores and moisture evaporation becoming higher (Hao *et al*., 2014).

3.3 FTIR profile of gadung tuber pasta

The functional group of gadung tuber pasta after the drying process was investigated using FTIR analysis. The FTIR spectra of gadung tuber pasta with various formulations of protein content can be seen in Figure 3. The FTIR spectra showed the different values of transmittance from the functional group, the carbonyl groups (C=O) and the hydroxyl groups (O-H). The two groups were identified at wavelengths of 1500–2000 and 2500–3000 cm^{-1} and correlated with the water affinity (Yang *et al*., 2021). The highest peak was found in gadung tuber pasta with high protein wheat flour indicating that the hydrogen bonds were strongest than others.

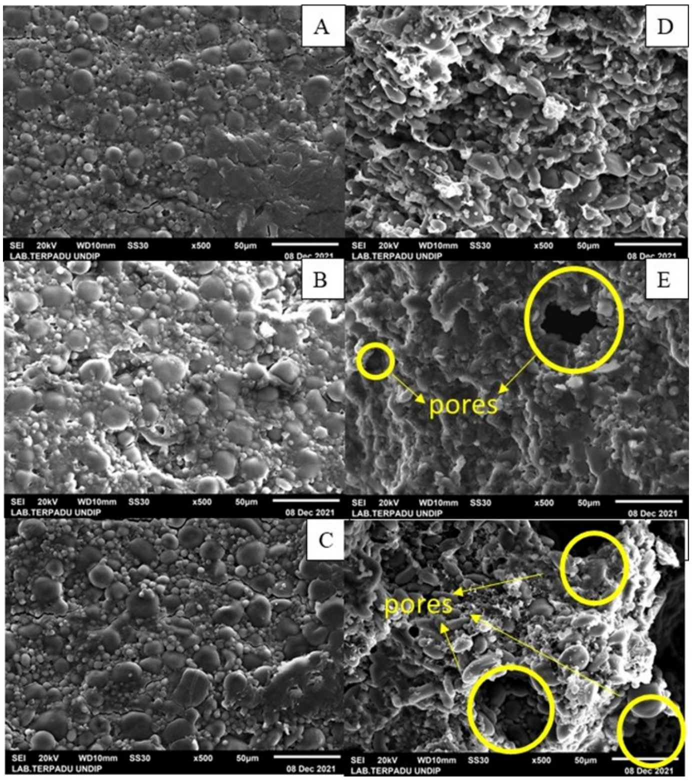

Figure 2. Surface morphology on gadung pasta with high protein wheat flour (A), medium protein wheat flour (B), low protein wheat flour (C), and cross-sectional image on gadung tuber pasta with high protein wheat flour (D), medium protein wheat flour (E), low protein wheat flour (F).

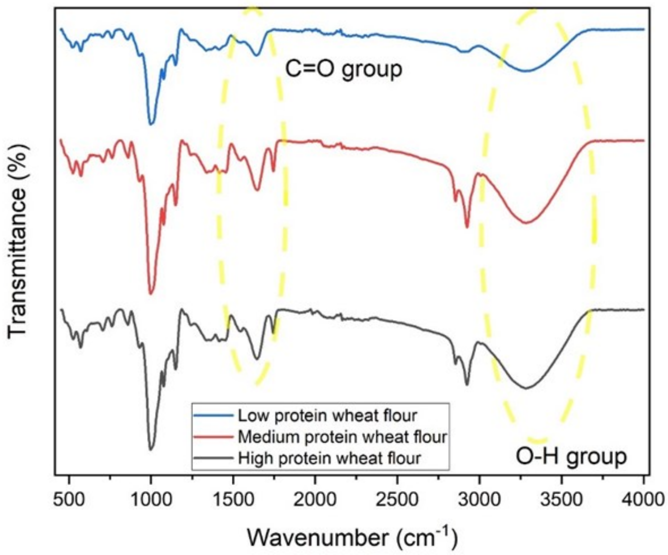

Figure 3. Comparison of FTIR spectra on samples of gadung tuber pasta with various formulations of protein content in wheat flour.

3.4 Effect of the drying temperatures and variation of protein content in wheat flour

The reduction of moisture content in gadung tuber pasta was observed every 30 mins for 240 mins (Figure 4A-4C). For all the pasta formulations, at the same drying time, the higher temperatures resulted in the

https://doi.org/10.26656/fr.2017.8(S1).5

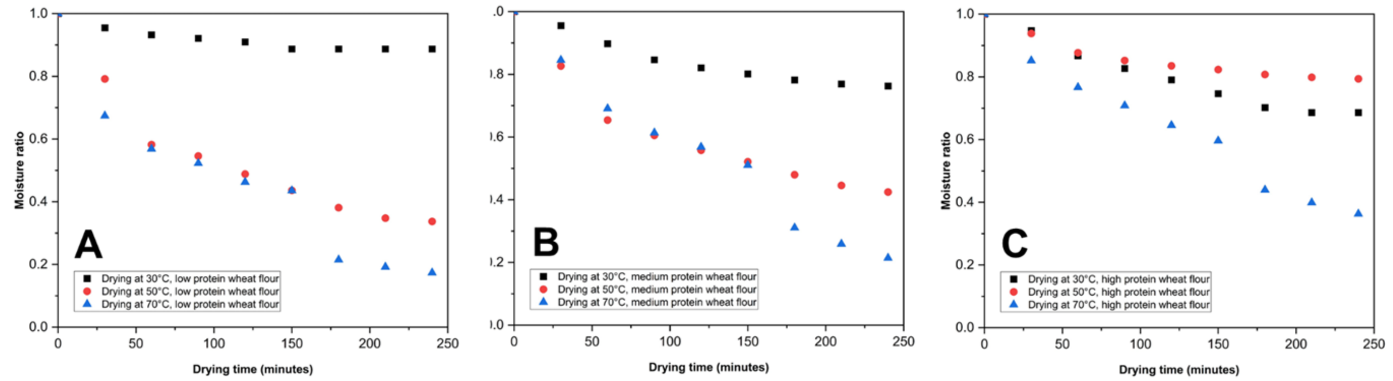

Figure 4. Moisture ratio observation of low protein wheat flour (A), medium protein wheat flour (B), and high protein wheat flour (C) at different drying temperatures (30, 50, and 70°C).

lower moisture content. For example, in drying with low-protein wheat flour (Figure 4A), increasing the drying temperature from 30°C to 50°C, the final moisture content becomes 2.6 times lower. At high drying temperatures, the drying driving force can increase so that drying becomes faster (Sasongko *et al*., 2020).

The protein content in wheat flour affects water content reduction. In all variations of drying temperature, the pasta with low protein content resulted in lower moisture content. For example, at a drying temperature of 50°C, the moisture content in the pasta with low protein wheat flour was 1.26 times lower than the pasta with medium protein wheat flour. Additionally, the moisture content in the pasta with low protein wheat flour was 2.35 times lower than the pasta with high protein wheat flour. The protein that are naturally hydrophilic are easily bonds with the water molecules and forms hydrogen bonds. Then, the flour with a high protein content has a high water holding capacity and decreases water mobility, preventing the evaporation of water during the drying process (Hao *et al*., 2014; Li *et al*., 2018). This result was in line with SEM analysis which showed the compact surface of pasta with high protein wheat flour (Figure 2). While the pasta with low protein wheat flour consisted of pores in the cross-sectional image. Thereby implying that the hydrogen bonding in the pasta with high protein wheat flour was tight and decrease the water mobility during the drying process. This was also in line with FTIR analysis, the O-H peak was higher in the pasta with high protein wheat flour (Figure 3).

3.5 Kinetic model development

The kinetics of gadung tuber pasta drying at various drying temperatures and formulations were fitted into four thin layer models. The model constant and the statistical parameter on the gadung tuber pasta drying were listed in Table 2. The statistical parameter, the coefficient of determination (R^2), and Root Mean Square Deviation (RSMD) were used to look for the preferable model to describe the kinetic of gadung tuber pasta drying. Based on the statistical analysis, the model with the highest value of R^2 and the lowest value of RSMD was the Logarithmic model. The comparison between the logarithmic model and the experimental data was displayed in Figure 5. As seen in Figure 5, the logarithmic models show a good fit to the experimental values. Considering the Logarithmic model was also selected to describe the drying phenomenon in several food products: thyme leaves (Turan and Firatligil, 2019), green bell paper (Doymaz and Ismail, 2010), plum (Goyal *et al*., 2007) and pineapple (Kingsly *et al*., 2009).

4. Conclusion

The results of the drying process of onion bulbs at various temperatures (40, 50, 60 and 70°C) showed that drying onions using the rotary dryer method can increase the drying rate so that the process of reducing the moisture content can occur faster than with the chamber and tray dryer method. Furthermore, Page's model,

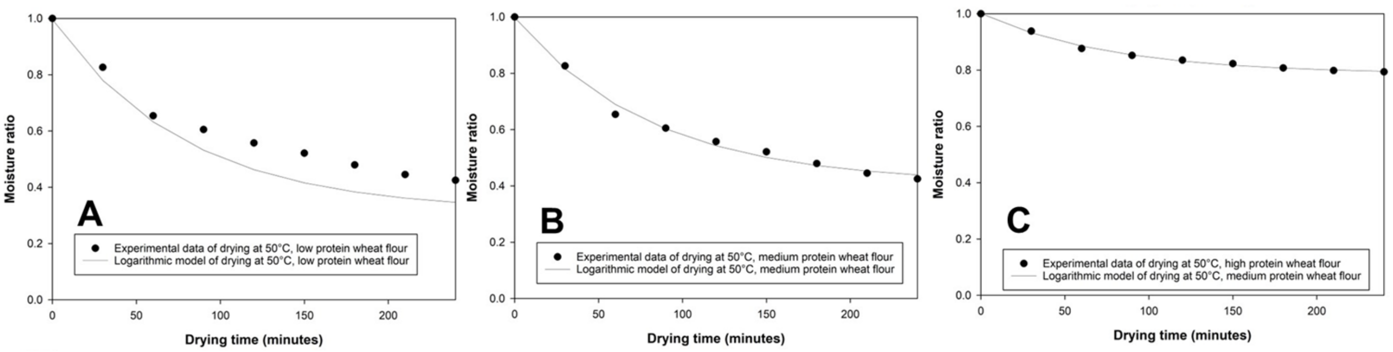

Figure 5. Moisture ratios comparison via experimental data and logarithmic model of low protein wheat flour (A), medium protein wheat flour (B), and high protein wheat flour (C) at different drying temperatures 50°C.

Table 2. Model constant and statistical parameter on thin layer drying of gadung tuber pasta.

Model	Protein content in wheat flour	Drying temperature (°C)	Model constant				R^2	RMSD
			k	n	a	c		
Newton	Low	30	0.001				0.681	0.007
		50	0.006				0.919	0.019
		70	0.007				0.933	0.022
	Medium	30	0.001				0.911	0.008
		50	0.004				0.896	0.019
		70	0.006				0.969	0.015
	High	30	0.002				0.965	0.007
		50	0.001				0.767	0.011
		70	0.004				0.978	0.010
Page	Low	30	0.011	0.445			0.975	0.002
		50	0.005	0.925			0.934	0.010
		70	0.021	0.784			0.951	0.019
	Medium	30	0.007	0.677			0.977	0.004
		50	0.029	0.622			0.989	0.006
		70	0.003	1.114			0.973	0.014
	High	30	0.005	0.802			0.985	0.004
		50	0.016	0.501			0.981	0.003
		70	0.004	1.029			0.979	0.010
Henderson and Pabis	Low	30	0.000		0.972		0.842	0.005
		50	0.005		0.925		0.934	0.016
		70	0.007		0.937		0.944	0.020
	Medium	30	0.001		0.975		0.937	0.007
		50	0.004		0.925		0.932	0.016
		70	0.007		0.937		0.944	0.020
	High	30	0.002		0.982		0.972	0.006
		50	0.001		0.958		0.874	0.008
		70	0.004		0.994		0.979	0.010
Logarithmic	Low	30	0.013		0.119	0.879	0.985	0.001
		50	0.001		0.682	0.313	0.989	0.007
		70	0.007		0.940	-0.003	0.944	0.020
	Medium	30	0.009		0.285	0.722	0.994	0.002
		50	0.012		0.589	0.409	0.992	0.005
		70	0.003		1.668	-0.690	0.979	0.012
	High	30	0.006		0.440	0.567	0.992	0.003
		50	0.013		0.215	0.786	0.996	0.001
		70	0.002		1.580	-0.603	0.983	0.009

which has an R^2 value of 0.991 and X^2 of 0.00027 can accurately describe the drying rate of onion bulbs.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

The authors would like to express their gratitude to Diponegoro University for their financial support through several research grants from which this paper was sourced.

References

Aregbesola, O.A., Ogunsina, B., Sofolahan, A.E. and Chime, N.N. (2015). Mathematical modeling of thin layer drying characteristics of dika *(Irvingia gabonensis)* nuts and kernels. *Nigerian Food Journal*, 33(1), 83–89. https://doi.org/10.1016/j.nifoj.2015.04.012

Arora, S., Bharti, S. and Sehgal, V.K. (2006). Convective Drying Kinetics of Red Chillies. *Drying Technology,* 24(2), 189–193. https://doi.org/10.1080/07373930600559068

Azizpour, M., Mohebbi, M., Khodaparast, M.H.H. and

https://doi.org/10.26656/fr.2017.8(S1).5

Varidi, M. (2013). Foam-mat drying of shrimp: Characterization and drying kinetics of foam. *Agricultural Engineering International: CIGR Journal*, 15(3), 159–165.

Bandna Address, C. and Chand, B. (2012). Effect of Processing on the Cyanide Content of Cassava Products in Fiji. *Journal of Microbiology*, 13(2), 947–958.

Doymaz, I. and Ismail, O. (2010). Drying and rehydration behaviors of green bell peppers. *Food Science and Biotechnology,* 19, 1449–1455.

Ertekin, C. and Firat, M.Z. (2017). A comprehensive review of thin-layer drying models used in agricultural products. Critical Reviews in *Food Science and Nutrition*, 57(4), 701–717. https://doi.org/10.1080/10408398.2014.910493

Goyal, R.K., Kingsly, A.R.P., Manikantan, M.R. and Ilyas, S.M. (2007). Mathematical modelling of thin layer drying kinetics of plum in a tunnel dryer. *Journal of Food Engineering*, 79(1), 176–180. https://doi.org/10.1016/j.jfoodeng.2006.01.041

Hao, F., Lu, L. and Ge, C. (2014). Effect of Fat Content on Water Sorption Properties of Biscuits Studied by Nuclear Magnetic Resonance. *Journal of Food and Nutrition Research,* 2(11), 814–818. https://doi.org/10.12691/jfnr-2-11-9

Jian, F. and Jayas, D.S. (2018). Characterization of isotherms and thin-layer drying of red kidney beans, part i: Choosing appropriate empirical and semitheoretical models. *Drying Technology*, 36(14), 1696–1706. https://doi.org/10.1080/ 07373937. 2017. 1422515

Kamalakar, D., Rao, L.N., Kumar, P.R. and Rao, M.V. (2014). Drying Characteristics of Red Chillies: Mathematical Modelling and Drying Experiments. *International Journal of Engineering Sciences and Research Technology*, 3(7), 425–437.

Kingsly, A.R.P., Balasubramaniam, V.M. and Rastogi, N.K. (2009). Effect of high-pressure processing on texture and drying behavior of pineapple. *Journal of Food Process Engineering,* 32(3), 369–381. https://doi.org/10.1111/j.1745-4530.2007.00221.x

Kumoro, A.C. and Hartati, I. (2015). Microwave Assisted Extraction of Dioscorin from Gadung (*Dioscorea hispida* Dennst) Tuber Flour. *Procedia Chemistry,* 14, 47–55. https://doi.org/10.1016/ j.proche.2015.03.009

Kumoro, A.C., Retnowati, D.S., Budiyati, C.S., Manurung, T. and Siswanto. (2012). Water solubility, swelling and gelatinization properties of raw and ginger oil modified gadung (*Dioscorea hispida* dennst) flour. *Research Journal of Applied Sciences, Engineering and Technology*, 4(17), 2854–2860.

Latif, S., Zimmermann, S., Barati, Z. and Müller, J. (2019). Detoxification of Cassava Leaves by Thermal, Sodium Bicarbonate, Enzymatic, and Ultrasonic Treatments. *Journal of Food Science*, 84 (7), 1986–1991. https://doi.org/10.1111/1750-3841.14658

Li, L., Wang, N., Ma, S., Yang, S., Chen, X., Ke, Y. and Wang, X. (2018). Relationship of Moisture Status and Quality Characteristics of Fresh Wet Noodles Prepared from Different Grade Wheat Flours from Flour Milling Streams. *Journal of Chemistry*, 2018, 7464297. https://doi.org/ 10.1155/2018/7464297

Mihindukulasuriya, S.D.F. and Jayasuriya, H.P.W. (2013). Mathematical modeling of drying characteristics of chilli in hot air oven and fluidized bed dryers. *Agricultural Engineering International: CIGR Journal,* 15(1), 154–166.

Mujumdar, A.S. (2006). Principles, Classification, and Selection of Dryers Arun. Handbook Industrial Drying. 3rd ed. USA: Taylor and Francis Group, LLC.

Nugroho, L.H. and Estyaniyana, A. (2018). The potency of gadung (*Dioscorea hispida* Dennst.) tuber as a functional food: Toxicity, phytochemical content and starch characters. *AIP Conference Proceedings*, 2002, 020037. https://doi.org/10.1063/1.5050133

Odoemelam, C.S., Percival, B., Ahmad, Z., Chang, M.W., Scholey, D., Burton, E., Okafor, P.N. and Wilson, P.B. (2020). Characterization of yellow root cassava and food products: Investigation of cyanide and β-carotene concentrations. *BMC Research Notes*, 13, 333. https://doi.org/10.1186/s13104-020-05175-2

Sasongko, S.B., Hadiyanto, H., Djaeni, M., Perdanianti, A.M. and Utari, F.D. (2020). Effects of drying temperature and relative humidity on the quality of dried onion slice. *Heliyon*, 6(7), e04338. https://doi.org/10.1016/j.heliyon.2020.e04338

Soesilowati, E., Kariada, N. and Paramita, O. (2019). Improving Non-wheat Flour Quality As a Form of Local Food Conservation. *KnE Social Sciences*, 2019, 146–156. https://doi.org/10.18502/ kss.v3i18.4708

Tavakolipour, H. and Mokhtarian, M. (2015). Drying of chili pepper in different conditions. *Proceedings of The IRES 4th International Confererence,* 2015, 71–74.

Turan, O.Y. and Firatligil, F.E. (2019). Modelling and characteristics of thin layer convective air-drying of thyme (*Thymus vulgaris*) leaves. *Czech Journal of*

Food Sciences, 37(2), 128–134. https://doi.org/10.17221/243/2017-CJFS

Widiyanti, M. and Kumoro, A.C. (2017). Kinetika detoksifikasi umbi gadung (*Dioscorea hispida* dennst.) secara fermentasi dengan kapang mucor racemosus. *Reaktor*, 17(2), 81–88. https://doi.org/10.14710/reaktor.17.2.81-88 [In Bahasa Indonesia].

Wrigley, C., Corke, H. and Walker, C.E. (2004). Encyclopedia of grain science. USA: Academic Press.

Yang, H., Boucly, A., Gabathuler, J.P., Bartels-Rausch, T., Artiglia, L. and Ammann, M. (2021). Ordered Hydrogen Bonding Structure of Water Molecules Adsorbed on Silver Iodide Particles under Subsaturated Conditions. *Journal of Physical Chemistry C*, 125(21), 11628–11635. https://doi.org/10.1021/acs.jpcc.1c01767

Yogendrasasidhar, D. and Setty, Y.P. (2019). Experimental studies and thin layer modeling of pearl millet using continuous multistage fluidized bed dryer staged externally. *Engineering Science and Technology, an International Journal*, 22(2), 428–438. https://doi.org/10.1016/j.jestch.2018.10.010

.

