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SINGLE-LAYER DRYING OF PURPLE YAM (*DIOSCOREAALATA* L.) SLICES

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Abstract

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This research was intended to find the best fitted model to represent the drying behaviors of purple yam slices during single-layer drying process. The research was conducted at Food Processing Laboratory of Agricultural Engineering Department, Hasanuddin University – Indonesia. Two levels of drying temperature (40 and 50°C) under two different air velocities (1.0 and 2.0 m.s^{-1}) were applied. A tray dryer (Model EH-TD-300 Eunha Fluid Science) was utilized as the main equipment. The moisture ratios resulted from each drying treatment combination was determined and nine different thin-layer models were fitted to these moisture ratios. The results indicated that all models performed well as shown by their high R^2 values (> 0.9) with small χ^2 and *RMSE* values. However, among all models, the Midili-Kucuk model consistently showed the best goodness of fit. It was also found that air velocity affected the drying rate of the purple yam slices. Another finding, the drying rates resulted from the drying air temperature of 50°C with the air velocity of 1.0 m.s^{-1} and the drying air temperature of 40°C with the air velocity of 2.0 m.s^{-1} were relatively close.

Key words: purple yam; single-layer drying; moisture ratio

Introduction

Yam has been suggested to have nutritional superiority compared to other tropical root crops. Arinathan et al. (2009) reported that yam is a good source of essential dietary nutrients. Trustinah and Kasno (2013) also indicated that yam contains glycoprotein and polysaccharide compounds which are effective to lower total cholesterol level. This crop has been known for a long time in Indonesia but its popularity has been fading due to the existence of more economical food crops.

Several studies have been conducted on this crop. Among others, Hsu et al. (2003) explored the effects of drying methods on yam flour quality parameters such as proximate composition, physical properties and antioxidant activities. In their study, slices of yam tubers (2 cm thickness) were dried using freeze-drying, hot air-drying, and drum-drying. Results reported by the authors indicated that the drying methods applied had significant effects on moisture contents but no marked effects on other components of yam flours. Indrastuti et al. (2012) studied the influence of pre-drying soaking and drying temperature on physicochemical characteristics of water yam flour. The levels of soaking time (0, 24, and 48 hours) and three levels of drying temperature (40, 50, and 60°C) were used in the study. Torres et al. (2012) used a horizontal air flow dryer and observed the kinetics and drying conditions of two yam varieties. The samples used in their study were cut into two shapes (circular with a radius of 3.19 cm and square with side dimension of 5.6 cm). The authors applied drying air temperatures of 40, 55 and 70°*C* under a constant velocity of 0.7 m.s^{-1}. The results reported by the authors indicated that of the three models evaluated in their study (Fick, Page, and Logarithmic models), the Logarithmic model was found to provide the best fit to experimental data.

This research was intended to enrich scientific information concerning drying behaviors of purple yam slices during thin-layer drying process. Unlike the previous studies, this research

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applied two levels of drying temperature (40 & 50°C) and two levels of air velocity (1.0 and 2.0 $m.s^{-1}$). These conditions were expected to appropriately represent the combination of low temperature and high drying air velocity.

Materials and Methods

Ten clusters of irregular shape yam tubers were obtained directly from a farmer in Bone Regency – South Sulawesi Province, Indonesia. Two clusters from the sample source (Figure 1) were selected and manually peeled before being sliced into squares using a sharp knife. The size and weight of each slice was about 20 x 20 x 3 mm and 1.7 to 2.0 g, respectively. The yam slices were placed in a plastic bag and stored in a refrigerator until use. For each experimental run, 40 slices were taken out from the refrigerator and allowed to equilibrate to room temperature prior to the drying process. This sample was then divided into two sub-samples, 20 slices each, and arranged into two separate trays.

Fig. 1. Yam sample used in this research

Main equipment

The tray dryer (Model EH-TD-300 Eunha Fluid Science) utilized in this research has been described in our previous study (Muhidong et al., 2013). The dryer was designed as a parallel air flow dryer in whom the drying-air flows horizontally and parallel to sample trays. The drying air velocity was measured using a portable digital anemometer (0.1 $m.s^{-1}$ accuracy) which was positioned at the air outlet of the dryer. The sub-sample weight across drying time was measured using a digital balance with an accuracy of 0.01 g. At the end of each drying run, the sub-sample was further dried in an electric oven to obtain its dry weight.

Experimental procedure

The experiment was performed at the Processing Laboratory of Agricultural Engineering Department, Hasanuddin University – Indonesia, during the period of May to July 2013. Two levels of drying temperature (40 and 50°C) under two different air velocities (1.0 and 2.0 $m.s^{-1}$) were applied. This approach resulted in four treatment combinations. Two drying runs were exercised for each treatment combination and sample for each drying run was divided into two sub samples. As a result, each treatment combination produced four data sets. Such a design was intended to increase the accuracy of the measurement.

The drying temperature and air velocity were stabilized for about one hour before the two sub-samples were loaded into the dryer. The initial weight of each sub-sample was recorded prior to the loading process. The weight of the sub-sample was recorded for every half hour elapsed drying time. The sub-sample was unloaded from the drying chamber any time the weighing process was carried out. The drying process was terminated when the weight of the sub-samples had been steady for about one hour. It was assumed that at this point time the sub-sample weight was in an equilibrium stage. The sub-samples were then oven-dried to get their dry weight. The dry-basis moisture contents (Mc_{db}) of the sub-sample across elapsed drying time were calculated for each drying temperature and air velocity combination. The average moisture content of the two sub-samples for the two drying runs under the same condition was calculated and designated as the calculated Mc_{db}.

Model performance evaluation

The calculated Mc_{db} for every half hour elapsed drying time of each treatment combination was transformed into moisture ratio ($MR_{(t)}$) using the following formula:

$$MR_{(t)} = \frac{Mc_{db(t)} - Me}{Mo - Me},$$

where Mo, $Mc_{db(t)}$, and Me respectively represents the initial Mc_{db} (% dry basis), the Mc_{db} at elapsed drying time t (% dry basis), and the equilibrium moisture content (% dry basis). It is important to note that the final Mc_{db} of each treatment combination was taken as the equilibrium moisture content of each sample under the corresponding treatment combination.

The behaviors of the $MR_{(t)}$ across the drying time were fitted to the thin layer drying models available in Table 1. These models have been applied previously by Muhidong et al. (1992), Corrêa et al. (2006), Kingsly et al. (2007), Yadollahinia et al. (2008), Hii et al. (2008), Ibrahim et al. (2009), Meisami-asl et al. (2009), Muhidong (2011), Torres et al. (2012), Rayaguru and Routray (2012), Muhidong et al.

Table 1
Thin-layer drying models tested in this research

No	Model Name	Equation	References
1	Newton	$MR_{(t)} = \exp(-a.t)$	Muhidong et al. (2011)
2	Henderson and Pabis	$MR_{(t)} = a.\exp(-b.t)$	Ibrahim et al. (2009)
3	Page	$MR_{(t)} = \exp(-a.t^b)$	Corrêa et al. (2006)
4	Midilli-Kucuk	$MR_{(t)} = a \exp(-k.t^d) + b.t$	Hii et al. (2008)
5	Two term model	$MR_{(t)} = a.\exp(-b.t) + k.\exp(-d.t)$	Meisami-asl et al. (2009)
6	Diffusion approach	$MR_{(t)} = a.\exp(-b.t) + (1-a).\exp(-b.k.t)$	Yadollahinia et al. (2008)
7	Hii *et al.*	$MR_{(t)} = a.\exp(-b.t^k) + d.\exp(-e.t^k)$	Hii et al. (2008)
8	Logarithmic	$MR_{(t)} = a.\exp(-k.t) + d$	Torres et al. (2012)
9	Wang & Singh	$MR_{(t)} = 1 + a.t + b.t^2$	Kingsly et al. (2007)

Note: t represents elapse drying time (in half hour) and a, b, k, d, and e are drying constants

(2013), and Boyar et al. (2013). Nag and Dash (2016) also used these models to study the thin layer drying kinetics and moisture diffusivity of elephant apple.

All the models in Table 1 were fitted to *MR* values across the elapsed drying time. Microsoft Excel Solver was utilized to solve the non-linear models in Table 1 to obtain the values of the drying constants in each model. Hii et al. (2008) and Muhidong et al. (2013) also used this software to support their analysis. R^2, χ^2 and *RMSE* values were calculated to assess the goodness of fit of each individual model. The best model was chosen based on its R^2 value, Chi-squared (χ^2), and the Root Mean Squared Error (*RMSE*). R^2 value was determined using the RSQ function of the Microsoft Excel while Chi-square (χ^2) and *RMSE* values were estimated using the following equations (Mohammadi et al., 2008, Narayana et al., 2016, and Izli, 2017):

$$X^2 = \frac{\sum MR_{(\text{observed})} - MR_{(\text{predicted})}}{N - n}$$

$$RMSE = \sqrt{\frac{\sum (MR_{(\text{observed})} - MR_{(\text{predicted})})^2}{N}},$$

where N designates the number of observations and n symbolizes the number of drying constants in the model.

A model with the highest R^2 and at the same time generating the smallest χ^2 and *RMSE* values would be considered the most appropriate model to characterize the behavior of the purple yam slices during single-layer drying process at the specified drying temperature and air velocity combination.

Results and Discussion

The initial moisture content of the purple yam used in this study was around 83.4± 1.6% (w.b.). This was slightly lower than that used by Torres et al. (2012) where the average moisture content of their sample was about 87.7 ± 0.2% (w. b.). The final moisture contents (*Me*) obtained after the drying process ranged from about 8.4 to 12.3% (w.b.). Under the drying conditions employed in this study, moisture content reduction was found to reach an insignificant level after about 6 hours of drying time. This result is in line with the results reported by Torres et al. (2012) at drying temperatures of 40 and 55°C.

The behavior of the Moisture Ratio (*MR*) across the elapsed drying time is depicted on Figure 2. This figure clearly indicates that drying air velocity consistently affected the drying rate of the purple yam slices on both drying temperatures used. It can also be seen from the figure that the drying rate generated by the drying air temperature of 40°C with air velocity of 2.0 $m.s^{-1}$ was relatively close to that resulted from the drying air temperature of 50°C with air velocity of 1.0 $m.s^{-1}$.

The results of non-linier regression analysis from Microsoft Excel Solver for estimation of drying constants in each model are shown in Table 2. Results from Table 2 strongly

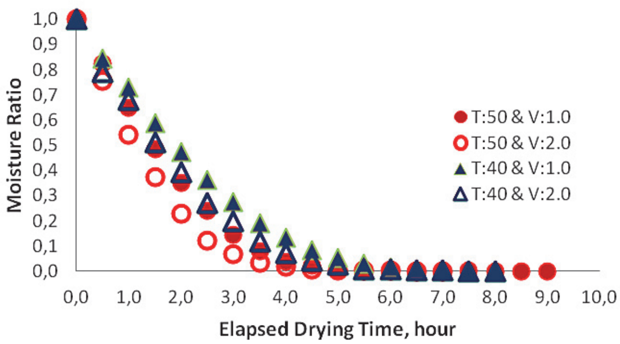

Fig. 2. Moisture Ratio (*MR*) across elapsed drying time

Table 2

Drying constants involved in the models being evaluated along with the values of R2, χ2 , and RMSE

Model Name	Equation	T and V	a	b	k	d	e	R^2	χ^2	RMSE
Newton	MR = exp(-a.t)		0.5682					0.9889	0.0019	0.0421
Henderson and Pabis	MR = a.exp(-b.t)		1.0673	0.6009				0.9873	0.0016	0.0375
Page	MR = exp(-a.t^b)		0.4228	1.3771				0.9989	0.0001	0.0103
Midilli-Kucuk	MC = a exp (-k.t^d) + b.t		0.9874	-0.0004	0.4092	1.3967		0.9990	0.0001	0.0096
Two term model	MR = a.exp(-b.t) + k.exp(-d.t)	50°C:1.0 ms^{-1}	0.5336	0.6009	0.5336	0.6009		0.9873	0.0018	0.0375
Diffusion approach	MR = a.exp(-b.t) + (1-a).exp(-b.k.t)		-13.7277	0.3336	1.0356			0.9917	0.0011	0.0298
Hii et al.	MR = a.exp(-b.t^k) + d.exp(-e.t^k)		0.4933	0.4080	1.4047	0.4933	0.4080	0.9990	0.0001	0.0097
Logarithmic	MR = a.exp(-k.t) + d		1.0901		0.5441	-0.0358		0.9893	0.0012	0.0315
Wang & Singh	MR = 1 + a.t + b.t^2		-0.3410	0.0270				0.9690	0.0040	0.0597
								0.9990	0.0001	0.0096
Model Name	Equation	T and V	a	b	k	d	e	R^2	χ^2	RMSE
Newton	MR = exp(-a.t)		0.7254					0.9927	0.0012	0.0337
Henderson and Pabis	MR = a.exp(-b.t)		1.0439	0.7527				0.9916	0.0011	0.0310
Page	MR = exp(-a.t^b)		0.6192	1.2883				0.9990	0.0001	0.0098
Midilli-Kucuk	MC = a exp (-k.t^d) + b.t		0.9921	-0.0006	0.4092	1.2928		0.9991	0.0001	0.0093
Two term model	MR = a.exp(-b.t) + k.exp(-d.t)	50°C:2.0 ms^{-1}	0.5336	0.7527	0.5220	0.7527		0.9916	0.0013	0.0310
Diffusion approach	MR = a.exp(-b.t) + (1-a).exp(-b.k.t)		-14.9649	0.4398	1.0306			0.9953	0.0006	0.0221
Hii et al.	MR = a.exp(-b.t^k) + d.exp(-e.t^k)		0.4957	0.6088	1.3032	0.4957	0.4080	0.9991	0.0001	0.0095
Logarithmic	MR = a.exp(-k.t) + d		1.0659		0.6865	-0.0326		0.9933	0.0008	0.0250
Wang & Singh	MR = 1 + a.t + b.t^2		-0.4327	0.0436				0.9707	0.0042	0.0606
								0.9991	**0.0001**	**0.0093**
Model Name	Equation	T and V	a	b	k	d	e	R^2	χ^2	RMSE
Newton	MR = exp(-a.t)		0.4415					0.9889	0.0025	0.0489
Henderson and Pabis	MR = a.exp(-b.t)		1.0694	0.4686				0.9853	0.0021	0.0435
Page	MR = exp(-a.t^b)		0.3049	1.3601				0.9981	0.0003	0.0151
Midilli-Kucuk	MC = a exp (-k.t^d) + b.t		0.9815	-0.0024	0.2915	1.3537		0.9988	0.0002	0.0113
Two term model	MR = a.exp(-b.t) + k.exp(-d.t)	40°C:1.0 ms^{-1}	0.5347	0.4686	0.5347	0.4686		0.9853	0.0025	0.0435
Diffusion approach	MR = a.exp(-b.t) + (1-a).exp(-b.k.t)		-11.8546	0.2146	1.0574			0.9944	0.0008	0.0255
Hii et al.	MR = a.exp(-b.t^k) + d.exp(-e.t^k)		0.4876	0.2810	1.4136	0.4876	0.2810	0.9984	0.0003	0.0135
Logarithmic	MR = a.exp(-k.t) + d		1.1367		0.3691	-0.0981		0.9932	0.0008	0.0264
Wang & Singh	MR = 1 + a.t + b.t^2		-0.3082	0.0234				0.9980	0.0002	0.0143
								0.9988	**0.0002**	**0.0113**
Model Name	Equation	T and V	a	b	k	d	e	R^2	χ^2	RMSE
Newton	MR = exp(-a.t)		0.5246					0.9902	0.0017	0.0406
Henderson and Pabis	MR = a.exp(-b.t)		1.0498	0.5475				0.9882	0.0016	0.0376
Page	MR = exp(-a.t^b)		0.4050	1.2948				0.9969	0.0004	0.0182
Midilli-Kucuk	MC = a exp (-k.t^d) + b.t		0.9773	-0.0015	0.3828	1.3115		0.9974	0.0003	0.0160
Two term model	MR = a.exp(-b.t) + k.exp(-d.t)	40°C:2.0 ms^{-1}	0.5249	0.5475	0.5249	0.5475		0.9882	0.0018	0.0376
Diffusion approach	MR = a.exp(-b.t) + (1-a).exp(-b.k.t)		-11.8531	0.2903	1.0456			0.9941	0.0007	0.0245
Hii et al.	MR = a.exp(-b.t^k) + d.exp(-e.t^k)		0.4868	0.3761	1.3476	0.4867	0.3761	0.9972	0.0004	0.0169
Logarithmic	MR = a.exp(-k.t) + d		1.0872		0.4683	-0.0579		0.9923	0.0009	0.0272
Wang & Singh	MR = 1 + a.t + b.t^2		-0.3449	0.0286				0.9906	0.0013	0.0339

indicate that all models can appropriately represent the behavior of *MR* across the elapsed drying time as indicated by high R^2 values (> 0.9) and small χ^2 and *RMSE* values. The results clearly indicate that the Midili-Kucuk model consistently performed better than the other models for all drying treatment combinations. It is also important to note that the study by Torres et al. (2012) found that Logarithmic model provides the best fit for their data. Nonetheless, it should be noted that the Midili-Kucuk model was not included in their study. Figure 3 provides perspectives regarding the degree of the goodness of fit of the Midili-Kucuk model in predicting the *MR* values across the elapsed drying time.

Conclusions

Although all models tested had a high degree of goodness of fit, the Midili-Kucuk model consistently performed well for all drying treatments applied in this research. It was also found that air velocity affected the drying rate of the purple yam slices. Drying rates of yam slices at drying air temperature of 50°C with air velocity of 1.0 m.s^{-1} were relatively close to those at drying air temperature of 40°C with the air velocity of 2.0 m.s^{-1}.

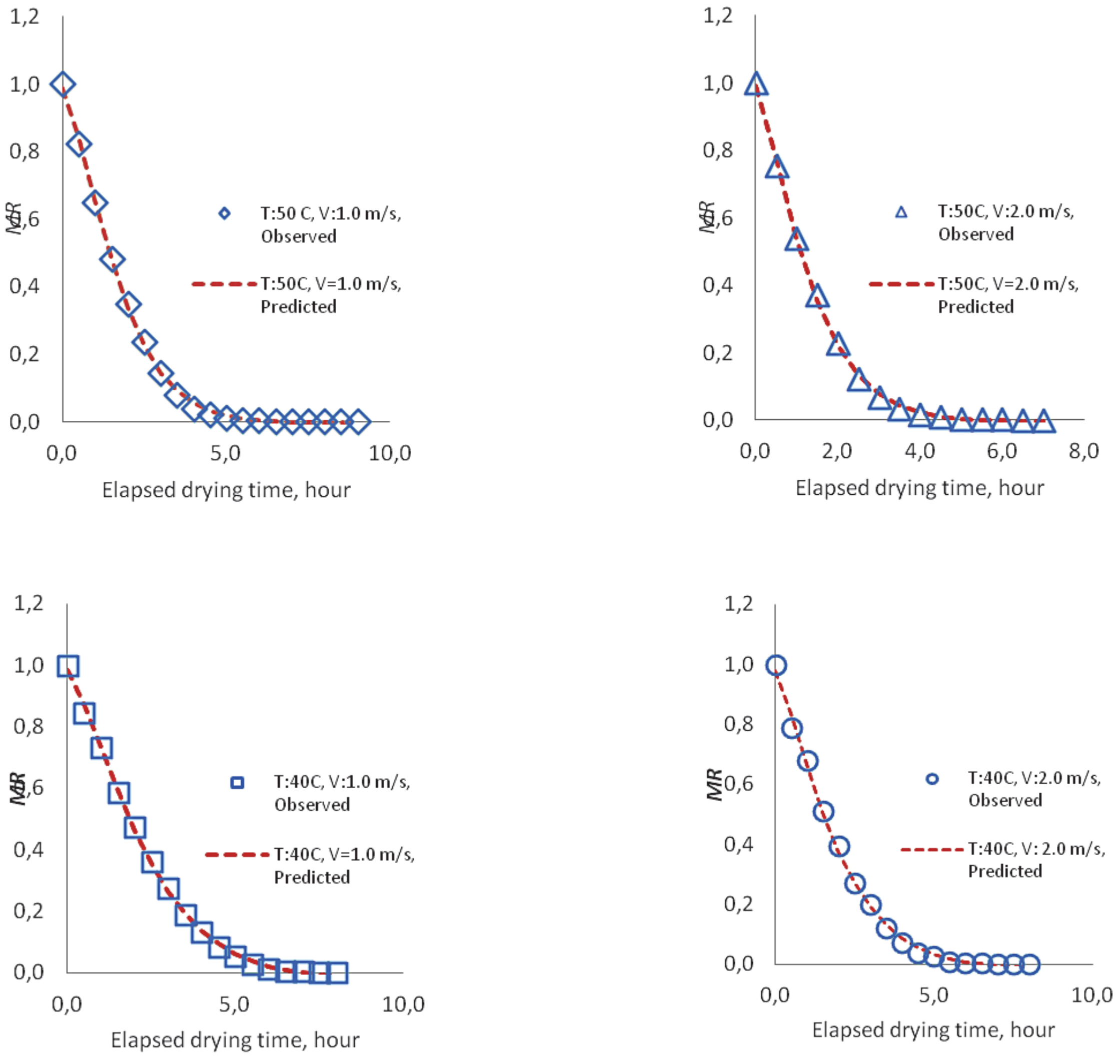

Fig. 3. Observed vs. Midili-Kucuk predicted *MR* values across elapsed drying time

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