SINGLE-LAYER DRYING BEHAVIOR OF RED CHILI

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ABSTRACT

This study was designated to determine the best model that could represent the behavior of the moisture content of cut red-chili, *Tombak* variety, during the single layer drying process. A Tray Dryer Model EH-TD-300 Eunha Fluid Science was used to support the experiment. The dryer was constructed to flow the drying-air parallel with the crop observed. Three levels of drying air velocity (1.0 m/s, 1.5 m/s, and 2.0 m/s) were applied under a constant drying air temperature of 47°C. The average relative humidity (RH) in the drying chamber during the drying period was around 39%. The results of this study strongly suggested that the Hii *et al.* (2008) model, $MR = 0.76832.\exp(-0.06607.t^{1.43089}) + 0.25351.\exp(-0.06881.t^{1.43089})$ and $MR = 0.76758.\exp(-0.10141.t^{1.47651}) + 0.30562.\exp(-0.10018.t^{1.47651})$, were the best model in predicting the moisture behavior of the cut chili, *Tombak* variety, across the elapsed drying time when the drying air velocities were set to 1.5 m/s and 2.0 m/s, respectively. However, the Diffusion Approach model, $MR = -0.02821.\exp(0.01340.t) + (1.02821)).\exp(-0.107576.t)$, was observed to be the best model at the drying air velocity of 1.0 m/s.

Keywords: single-layer drying, chili

INTRODUCTION

Chili is one of the strategic crops in Indonesia. Bank Indonesia (2007) reported that the average chili consumption in Indonesia, especially in Java island, was about 5.9 g/person/day or about 2.2 kg/person/year. Chili production in this country, as indicated by BPS (2010), was about 1.4 and 1.3 million tons in 2009 and 2010, respectively. About half of these productions were coming from East, West, and Central Java areas. South Sulawesi alone produced about 21 thousand tons in 2009 and about 27 thousand tons in 2010.

The moisture content of fresh chili can reach up to around 90% wet-basis. With such high moisture, chili becomes perishable. Tempo Interactive media reported that chili price in January 2011 hit Rp.100,000.-/kg. This price, however, sharply decreased down to about Rp.2,500,-/kg in May 2011, as indicated by the media interactive of Medan Bisnis on May 18, 2011. Price fluctuation was mostly dictated by the unbalance between demand and supply. To avoid such unbalance situation, the storage time of fresh chili should be improved or any excessive production is dried and kept at lower moisture content to allow a safe storage.

This study was focused to explore the single-layer drying characteristics of chili using a mechanical dryer. Similar studies were conducted by Tuntiwaranuruk and Mani (2009), and Toyosi *et al.* (2010), applying a constant air velocity at steady or various levels of drying temperature. In contrast, this research was exercised a fixed drying temperature with a range of air velocities.

RESEARCH METHODOLOGY

This research was carried out at the Crop Processing Laboratory of Agricultural Engineering Department, Hasanuddin University during the period of January to May 2011. Main equipment used was the Tray Dryer Model EH-TD-300 Eunha Fluid Science. The dryer was constructed to flow the drying-air parallel with the dried crop and equipped with wet and dry bulb thermometers in its drying chamber. A digital balance was applied to record the weight of the samples across elapsed drying period. Chili used was a *Tombak* variety, obtained from local chilifarmers in Gowa Regency, South Sulawesi. The initial moisture content was around 90% wet basis.

Three levels of air velocity, v, (1.0, 1.5, and 2.0 m/s) under a constant drying temperature of 47°C were applied in this research. The sample weight was recorded, using a digital balance, every one hour of elapsed drying time. Chili sample was cut across the length of its thick flesh and set aside its white spongy core and seeds. Before drying, all samples were blanched with hot water, 60°C for about 10 minutes. Each

sample was divided into two sub-samples to improve the accuracy of the observation. For each drying run, the dryer was loaded with two sub-samples of each sample arranging in a single layer batch in such away the thickness of the sample was about equal to the chili diameter. With this approach, the samples were exposed to the same drying air temperature and velocity. The weight of each sub-sample was around 100 g. The drying process was terminated when the weight of the sub-sample had reached a constant value for about 5 hours. The sub-sample was then oven-dried to get its dry weight. With this dry weight, the sub-sample weights across elapsed drying time were converted into a wet-basis and dry-basis moisture contents (Mc_{wb} and Mc_{db}). The average value of the moisture contents of the two sub-samples was taken to represent the moisture content of each sample for each drying condition. This was allowed to establish three Mc_{db} data sets, one set for each drying air velocity level. All calculated Mc_{db} were transformed into moisture ratio for elapse drying time ($MR_{(t)}$) using the following formula:

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

Where:

Mo   = Initial Mc_{db} (% dry basis)

$Mc_{(t)}$ = Mc_{db} at elapsed drying time t (% dry basis)

Me   = Equilibrium moisture content (% dry basis) using the final Mc_{db} of each drying run.

The characteristics of the moisture ratio across the drying time were then fitted to the thin layer drying models presented in Table 1. These models were used by Muhidong *et al.* (1992), Kingsly *et al.* (2007), Yadollahinia *et al.* (2008), Hii *et al.* (2008) and Ibrahim *et al.* (2009).

The values of each drying constant involved in the drying models was determined using a TABLECURVE 2D® V5.01 TRIAL VERSION extracted from http://www.sigmaplot.com/products/tablecurve2d/tablecurve2d.php   in March 2011. The best fitted model was selected based on its R^2, Chi-Squared, and RMSE values. A model with the highest R^2, and the lowest Chi-Squared and RMSE (Root Mean Squared Error) values will be considered as the best model to represent the behavior of the chili moisture contents during the single-layer drying process.

RESULTS AND DISCUSSIONS

The main result of this research was the behavior of the moisture contents across the elapsed drying time as shown in Figures 1 and 2. The first figure represented the reduction of the Mc_{wb} during the drying process. It also served as a drying curve in which surface and bound moistures can be located. This figure strongly indicated that a constant drying rate period, a process of releasing surface moisture, occurred prior to the elapsed drying times of around 25, 20, and 15 hours for v=1.0 m/s, v=1.5 m/s, and v=2.0 m/s, respectively. The falling rate then took place after these periods until the end of the drying time. The average relative humidity (RH) in the drying chamber during the drying period was about 39%.

Figure 2 provided information regarding the reduction pattern of the Mc_{db}. The exponential pattern was strongly demonstrated in this figure. The values of Mc_{db} at the end of each drying run which served as an equilibrium moisture content, Me, were found to be equal to 19.6%-db, 20.5%-db, and 14.7%-db for v=1.0 m/s, v=1.5 m/s, and v=2.0 m/s, respectively. This information was then used to determine the MR across the elapsed drying time for each drying run, Figure 3.

Table 1. Thin layer drying models tested in the experiment

No	Model Name	Equation[*)]
1	Newton	MR = exp(-a.t)
2	Henderson and Pabis	MR = a.exp(-b.t)
3	Modified Henderson and Pabis	MR = a.exp(-b.t) + c.exp(-d.t) + e.exp(-f.t)
4	Page	MR = exp(-a.t^b)
5	Modified Page	MR = exp(-(a.t)^b)
6	Two term model	MR = a.exp(-b.t) + c.exp(-d.t)
7	Verma *et al.*	MR = a.exp(-b.t) + (1-a).exp(-c.t)
8	Diffusion approach	MR = a.exp(-b.t) + (1-a).exp(-b.c.t)
9	Hii *et al.*	MR = a.exp(-b.t^c) + d.exp(-e.t^c)

[*)] Where **t** represents an elapse drying time (in hour) and **a, b, c, d, e**, and **f** are a drying constant.
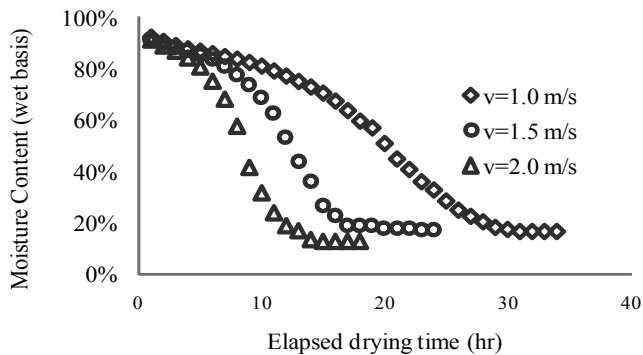
Figure 1.   Observed moisture content (wet-basis) across elapsed drying time
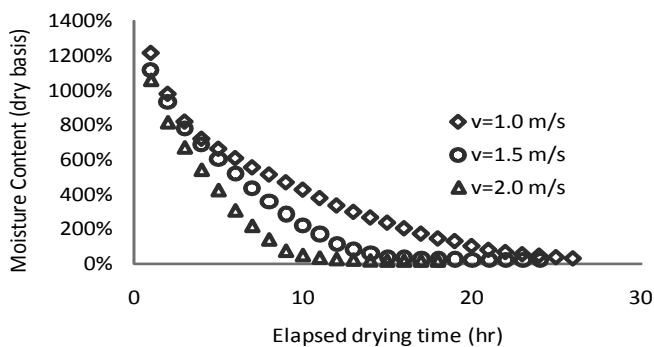

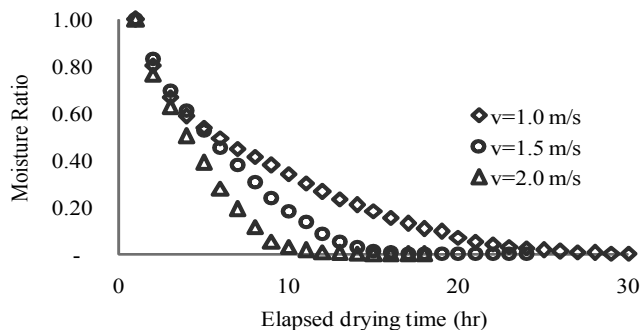Figure 2.   Observed moisture content (dry-basis) across elapsed drying time

Figure 3.   Trend of Moisture Ratio (MR) across elapsed drying time

The drying models were fitted to the MR data set across elapsed drying time and evaluated their goodness of fit. During the fitting process, drying constants involving in the models were calculated and their results were displayed in Table 1. This table also presented the R^2, Chi-squared and RMSE values.

The exponential pattern exhibited by the MR as shown in Figure 3 was undeniably relevant to all alternative models proposed in this study. It was also observed that the drying

rates resulted from three different drying air velocities as depicted in Figures 1 and 2 also confirmed that varying drying air velocities would affect the drying rates of cut chili. This phenomenon supported the argument that the goodness of fit evaluation of each model should be carried out on each drying run as shown in Table 2.

Based on the values of R^2, Chi-squared, and RMSE, it was obvious that the Hii *et al.*(2008) models, MR = 0.76832. exp(-0.06607.$t^{1.43089}$) + 0.25351.exp(-0.06881.$t^{1.43089}$) and MR = 0.76758.exp(-0.10141.$t^{1.47651}$) + 0.30562.exp(-0.10018. $t^{1.47651}$), were the best models to predict the behavior of the moisture contents of the cut chili, as represented by the MR values, across the elapsed drying time at high drying air velocity, 1.5 and 2.0 m/s respectively. Its R^2 values reached up to 0.99 with very small values of Chi-squared and RMSE, as low as 0.00049 and 0.01885. At lower drying velocity, v=1.0 m/s, however, the Diffusion Approach model, MR = -0.02821.exp(0.01340.t) + (1.02821)).exp(-0.107576.t), performed much better than the other models (R^2=0.99, Chi-squared=0.00072, and RMSE=0.02528). Figures 4, 5 and 6 demonstrated the goodness of fit of these two models in predicting the MR values across the elapsed drying time. Table 2 also showed that the Page model was the third best model after the Hii *et al.*(2008) and Diffusion Approach models.
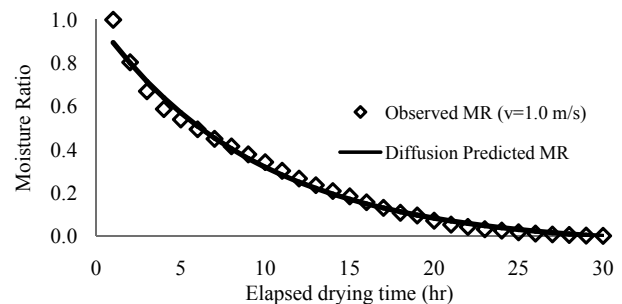

Figure 4.   Observed Moisture Ratio (MR) vs. predicted values of the Diffusion ApproachModel at the drying air velocity of 1.0 m/s
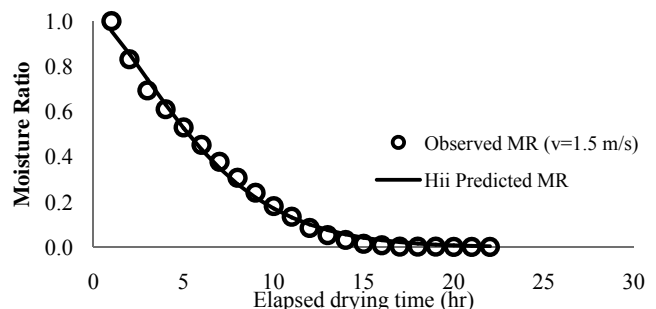

Figure 5.   Observed Moisture Ratio (MR) vs. predicted values of the Hii *et al.*(2008) Model at the drying air velocity of 1.5 m/s

Table 2. The values of drying constants, R^2, χ^2 (Chi-squared), and RMSE for each model evaluated at three levels of drying air velocity

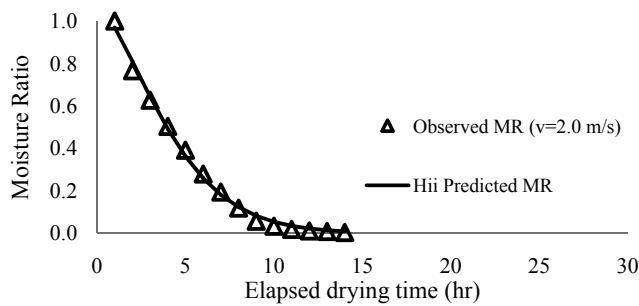| #	Evaluated Model	v (m/s)	a	b	c	d	e	f	R^2	χ^2	RMSE
1	Diffusion Approach	1.0	-0.02821	-0.01340	-8.02806				**0.9904**	**0.00072**	**0.02528**
		1.5	-0.09986	-0.00501	-24.69430				0.9744	0.00268	0.04729
		2.0	-0.10388	-0.00518	-32.40289				0.9568	0.00504	0.06259
2	Modified Henderson & Pabis	1.0	0.35288	0.12479	0.35288	0.12497	0.35288	0.12496	0.9875	0.00095	0.02889
		1.5	0.41754	0.19176	0.41754	0.19176	0.41754	0.19176	0.9850	0.00158	0.03627
		2.0	0.45575	0.27988	0.45575	0.27988	0.45755	0.27983	0.9865	0.00157	0.03497
3	Henderson & Pabis	1.0	1.05863	0.12479					0.9875	0.00089	0.02889
		1.5	1.25263	0.19176					0.9850	0.00143	0.03627
		2.0	1.36726	0.27986					0.9865	0.00138	0.03497
4	Hii *et.al.*	1.0	0.77944	0.11859	1.01892	0.26655	0.11681		0.9875	0.00098	0.02885
		1.5	0.76832	0.06607	1.43089	0.25351	0.06881		**0.9947**	0.00059	**0.02160**
		2.0	0.76758	0.10141	1.47651	0.30562	0.10018		**0.9961**	**0.00049**	**0.01885**
5	Newton	1.0	0.11827						0.9850	0.00103	0.03162
		1.5	0.15692						0.9524	0.00435	0.06454
		2.0	0.21319						0.9329	0.00644	0.07796
6	Modified Page	1.0	0.11617	1.07843					0.9872	0.00097	0.02922
		1.5	0.14699	1.47908					0.9945	0.00057	0.02183
		2.0	0.19904	1.64417					0.9949	0.00059	0.02140
7	Page	1.0	0.09812	1.07843					0.9872	0.00091	0.02922
		1.5	0.05866	1.47908					0.9945	**0.00052**	0.02183
		2.0	0.07037	1.64417					0.9949	0.00052	0.02140
8	Two Term	1.0	0.52931	0.12496	0.52931	0.12497			0.9875	0.00095	0.02889
		1.5	0.62631	0.19178	0.62631	0.19172			0.9850	0.00158	0.03627
		2.0	0.68362	0.27981	0.68362	0.27990			0.9865	0.00157	0.03497
9	Verma *et al.*	1.0	0.00330	397.450	0.12292				0.9830	0.00124	0.03360
		1.5	-3.04267	0.06944	0.08494				0.9786	0.00214	0.04330
		2.0	-3.67544	0.09560	0.11355				0.9621	0.00412	0.05860
						Max	**R^2**	**V1.0**	0.9904		
								V1.5	0.9947		
								V2.0	0.9961		
						Min	**χ^2**	**V1.0**		0.00072	
								V1.5		0.00052	
								V2.0		0.00049	
						Min	**RMSE**	**V1.0**			0.02528
								V1.5			0.02160
								V2.0			0.01885

Figure 6.   Observed Moisture Ratio (MR) vs. predicted values of the Hii *et al.*(2008) Model at the drying air velocity of 2.0 m/s.

The above result seemed to be different from the one reported by Tuntiwaranuruk and Mani (2009). These researchers discovered that the Page model was the best model for a thin-layer drying process of chili when the drying temperatures were set equal to 45, 50, 55, and 60ºC under a constant drying air velocity of 1.0 m/s. In their study, however, the Hii *et al.*(2008) and Diffusion Approach models were not parts of the models being evaluated. If these two models were included in their analysis, the results could have been similar to this study.

CONCLUSIONS

Among nine models evaluated, it was discovered that the Hii *et al*. (2008) model is the most appropriate model to represent the behavior of the moisture contents of the cut chili, *Tombak* variety, during the single-layer drying process with the drying air velocities of 1.5 and 2.0 m/s under a steady drying temperature of 47ºC. On the other hand, the Diffusion Approach model is found to be the most suitable model at the drying air velocity of 1.0 m/s.

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