EFFECT OF OVEN TEMPERATURE ON DRYING RATE OF DIFFERENT VARIETIES AND MATURITY OF PADDY

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ABSTRACT
Paddy drying is a key process in the production of good quality rice. In addition, reducing the moisture content to a level below microorganisms' growth requirement prevents the stored paddy from deteriorating. Temperature is one of the vital parameters in the drying process as it affects the moisture removal rate and consequently the quality of rice. The objective of this study was to determine the effect of oven temperature on the drying rate of paddy of different variety and maturity and to devise a mathematical model to represent its effect on the drying rate. The study was performed by heating 25g of paddy at different heating temperatures in an oven. Five different mathematical models were fitted into the data. The results showed that different levels of heating produced different drying rated. Drying time shortened as temperature increased. The highest drying rate provided 23.17% of weight loss and took 35 hours at 80°C. The exponential decay (double, four parameters) model (similar to two-term model) is suitable for drying Sarawak paddy and unripe local paddy. In contrast, ripe local paddy drying characteristic's data fit to exponential decay (single, three parameters) model.

Keywords: Drying, drying kinetics, drying model

INTRODUCTION

Rice is an essential carbohydrate source and also contributes to the economics of a country. The quality of rice is important and poor head rice and grain breakage have a serious effect on its value. To reach the standard quality of rice, it is well recognised that paddy drying is the best process to achieve the target. Moreover, quality deterioration because of microorganisms and natural respiration can be avoided by drying the freshly harvested paddy (Taechapairoj, Dhuchakallaya, Soponronnarit, Wetchacama, & Prachayawarakorn, 2003). In general, paddy drying is required for a long period before the paddy proceeds to the milling process when it becomes white rice. Some 18% of moisture content (w.b.) is necessary for storage in humid tropical conditions(Tumambing, 1993) and paddy is typically dried to 14% of moisture content before de-husking.

Theoretically, the drying operation, which constitutes the removal of water and involves diffusion of moisture from the kernel to the surrounding husk, could be achieved with heat supplied by convection (direct drying), conduction (indirect drying) or radiation. Conventional ovens rely on radiation from the oven wall, natural convection caused by the temperature gradient within the oven for transferring heat to the sample. According to previous findings, oven drying has been performed on thyme (Balladin & Headley, 1999) and onion (Arslan & Musa Özcan, 2010), but only at temperatures of 50ºC and 70ºC. Moreover, research on rough rice (paddy) was also done in an oven at temperatures of 110, 130, 150, and 170ºC(Jindal & Siebenmorgen, 1987).

In those previous studies, only long-grain rough rice was used in oven drying experiments. Furthermore, the temperature of the oven ranged between 110and 170ºC. Thus, the limited information available prompted this study to use different varieties of paddy and a different range of temperature to expand the findings. The main objective was to determine the effect of temperature on the drying rate of different paddy varieties and ripeness in an oven, and subsequently to devise a mathematical model to represent its effect on the drying rate.

MATERIALS AND METHODS

Experimental procedure

In this study, local varieties of paddy (Sarawak paddy, ripe Kampong paddy and unripe Kampong paddy) from Kota Belud in the north of Sabah, Malaysia were chosen as sample material. The initial moisture content of paddy (24 to 26% w.b.) was determined by a moisture analyser (Sartorius model MA35) with 0.01% readability. The paddy drying process was performed in an oven (MEMMERT UM 400) and operated in radiation and conduction drying condition with zero ventilation (no air flow). Twenty-five g of paddy sample was used and placed in a beaker. Each experiment was carried out in triplicate. The weight loss of paddy was determined by a gravimetric technique, in which the weight was monitored continuously. Weighing was performed on a digital balance (Sartorius TE 2145). Each weight loss was considered as moisture loss, and the moisture content on a wet basis (M) was calculated from Eq. (1):

$$M = W_0 - W_d \qquad (1)$$

Where W_0 and W_d are the initial weight of the sample (g) and the weight of the dried sample (g), respectively.

The temperature of the oven was adjusted to 40, 50, 60, 70 and 80°C to determine the drying pattern of fragrant paddy over time. The samples were allowed to remain inside and continue drying until there was no perceptible weight change, as evidenced by constant weight values (±0.001g). The total time required for removal, weighing and replacing the samples in the oven was approximately 30 s. This minimised the degree of atmospheric moisture sorption during weighting. This method was used previously by Al-Muhtaseb, McMinn, & Magee (2004).

Mathematical modelling of drying curves

The dimensionless variable of moisture ratio (MR) of paddy was calculated from Eq. (2):

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad (2)$$

Where M_t, M_0, and M_e are moisture content at any time, initial moisture content, and equilibrium moisture content, respectively. The values of M_e may be relatively small compared with M_t and M_0, so the equation can be simplified to MR = M/Mo (Akgun & Doymaz, 2005; Toğrul & Pehlivan, 2003; Thakor, Sokhansanj, Sosulski, & Yannacopoulos, 1999). Sigma Plot 10 software was utilised to operate non-linear least square regression analysis with five types of mathematical models to evaluate the model parameters. The selected mathematical models from Sigma Plot 10 software used to fit the data are presented in Table1. The goodness of fit of the tested mathematical models to the experimental data was evaluated with the correlation coefficient (R^2), reduced chi square (χ^2) and root mean square error (RMSE). The best fit was that which resulted in higher R^2 and the lowest χ^2 and RMSE (Ertekin & Yaldiz, 2004; Gunhan, Demir, Hancioglu, & Hepbasli, 2005; Özdemir & Onur Devres, 1999).

RESULTS AND DISCUSSION

The paddy sample was dried until very small changes (±0.001 g) in weight loss value were shown. As the weight decreases over time, it indicates that moisture inside the kernel diffused out to the surrounding husk. Two types of drying occur in a paddy structure, internal and external drying. External drying occurred on the surface of the paddy kernel, the hard cover known as hull. The drying rate of surface paddy was very high and prompted by exposure to insides of oven's surrounding which made the moisture easily evaporate. This explains the result in the graphs which show high weight loss in the early period of the drying process. According to the drying curve results, the paddy weight drop began to lessen after a certain time. Once the paddy weight loss rate began to decline, the moisture on the surface of the paddy hull decreased and limits the drying rate. In this context, internal drying had a strong influence. Internal drying happened when the moisture diffused from the endosperm section to the hull and then evaporated to the insides of oven's surrounding. The rate of internal drying was usually gradual since it entaileda moisture gradient between endosperm and hull. Once the moisture content on the hull surface increased, the diffusivity of moisture from the endosperm was limited as the moisture gradient of the hull surface decreased, hence reducing the drying rate (Cihan, Kahveci, & Hacıhafızoğlu, 2007) and weight loss of the paddy.

The fallingrate period occurred only in paddy with low moisture content throughout the entire drying process (Doungporn, Poomsa-ad, & Wiset, 2012), unlike guava, papaya, carrot, paprika and potato which have very high moisture content and capable on display constant-rate period in the drying process (Hawlader, Perera, Tian, & Yeo, 2006; Ramesh, Wolf, Tevini, & Jung, 2001). Drying temperature played the main role interms of moisture reduction in the fallingrate period. The results of the paddy drying experiment evidenced that drying rate and weight loss were affected by different drying temperatures. As shown in Figures 1, 2 and 3, five different drying patterns were achieved by different drying temperatures. The weight loss rate of paddy in 40ºC of drying temperature was at a moderate pace which required more than 75 hours to reach a state of equilibrium. However, the paddy weight loss rate began to rise as the temperature increased. The highest drying rate provided 23.17% weight loss at a temperature of 80ºC and required 35 hours to complete the drying, and more than 20 hours to achieve equilibrium.

In Table 1, five selected empirical models were used to fit the data experiment; exponential rise to max (single, three parameters), hyperbola (single rectangular, three parameters), hyperbola (hyperbolic decay, three parameters), exponential decay (single, three parameters), and exponential decay (double, four parameters). A non-linear square regression analysis was used to fit the five selected models with Sigma Plot 10 software and to determine the R^2 value of each model fitted;χ^2 and RSME were calculated with Microsoft Excel. The statistical results of the mathematical models are presented in Tables 2, 3 and 4.

It was observed that different species of paddy provided specific types of mathematical models which described the drying characteristics in Figure 4, 5 and 6. The exponential decay (double, four parameters) model is suitable for drying Sarawak paddy and unripe Kampong paddy in an oven with different temperatures and presents the highest value of R^2 with the lowest χ^2 and RMSE. In addition, the exponential decay (double, four parameters) model has a similar equation to that of the two-term drying model in the literature, $MR = a*e(-k_0t)+b*e(-k_1t)$ (Henderson, 1974). In contrast, ripe Kampong paddy data fit the exponential decay (single, three parameters) drying model. As observed, the weight loss of paddy is greatly increased by high temperature in the drying process. The highest drying rate was perceived at the beginning of the drying activity because of the high moisture content. Similarly, a trend towards moisture content reduction indicates diminution of the drying rate (Hawlader et al., 2006).

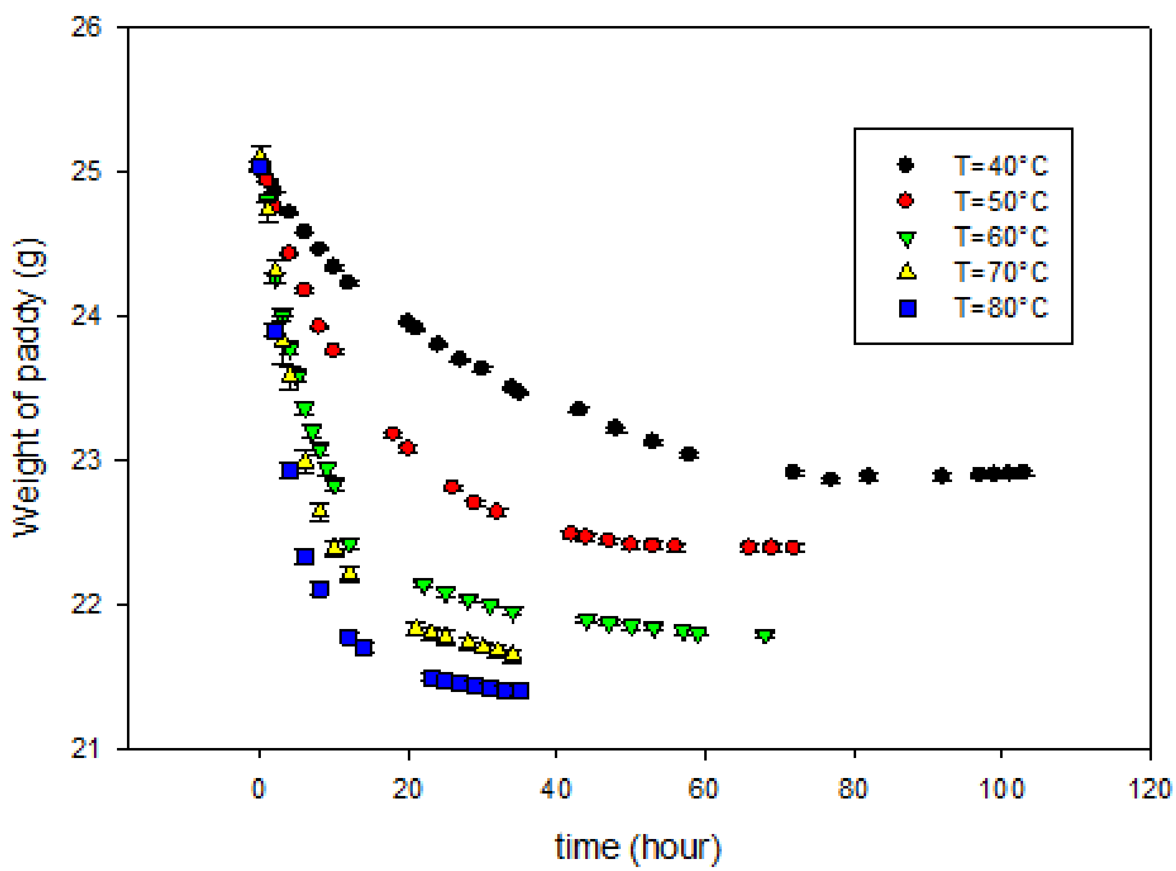

Figure 1: The weight of Sarawak paddy drying under different drying temperatures

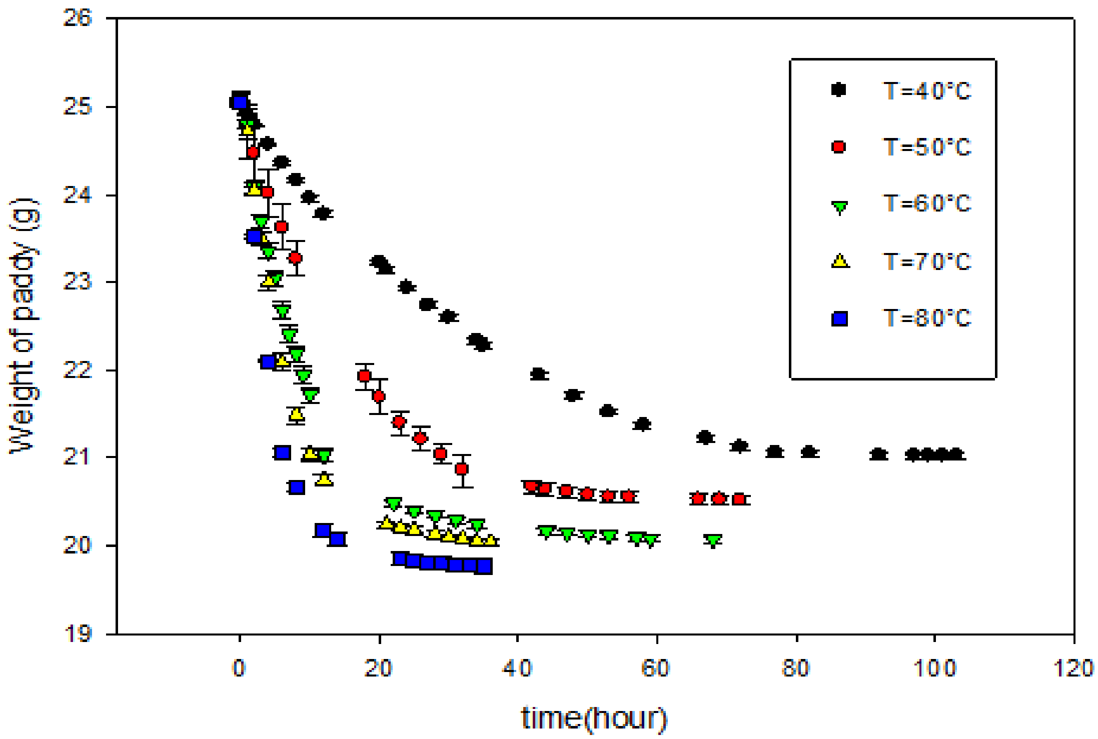

Figure 2: The weight of ripe Kampong paddy drying under different drying temperatures

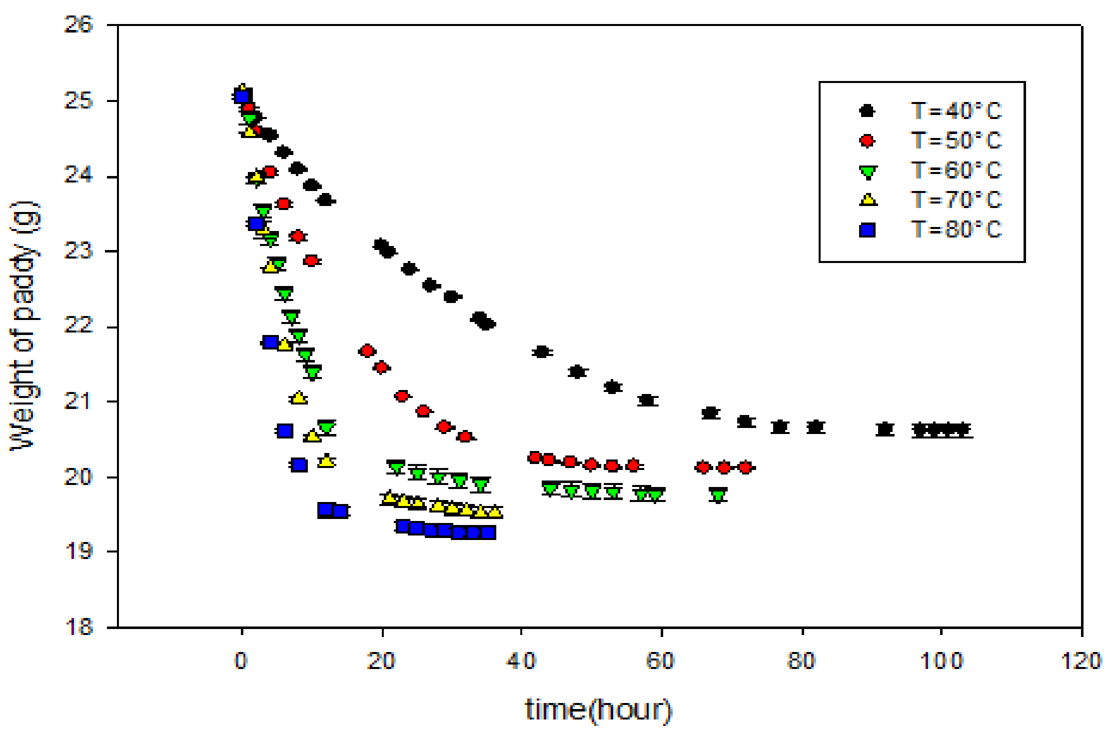

Figure 3: The weight of unripe Kampong paddy drying under different drying temperatures

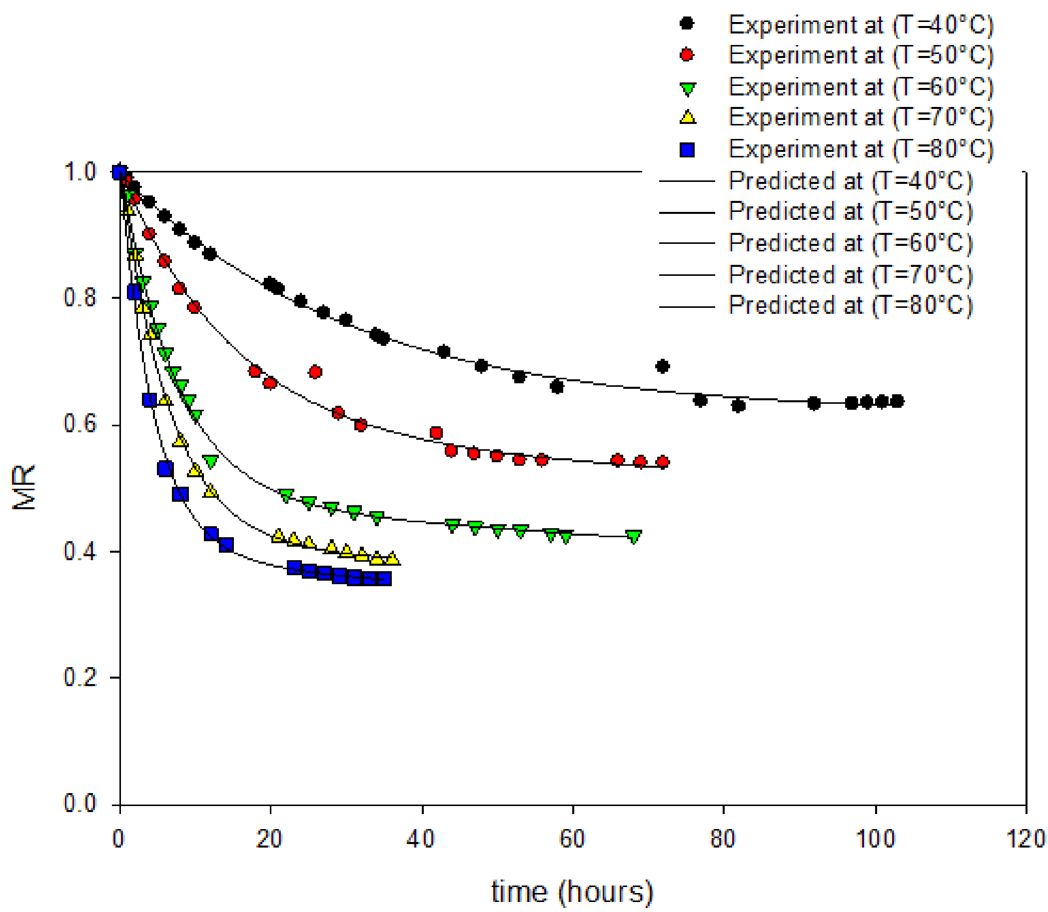

Figure 4: Experimental and predicted moisture ratio curves with drying time of Sarawak paddy under different drying temperatures with exponential decay (double, 4 parameters) model

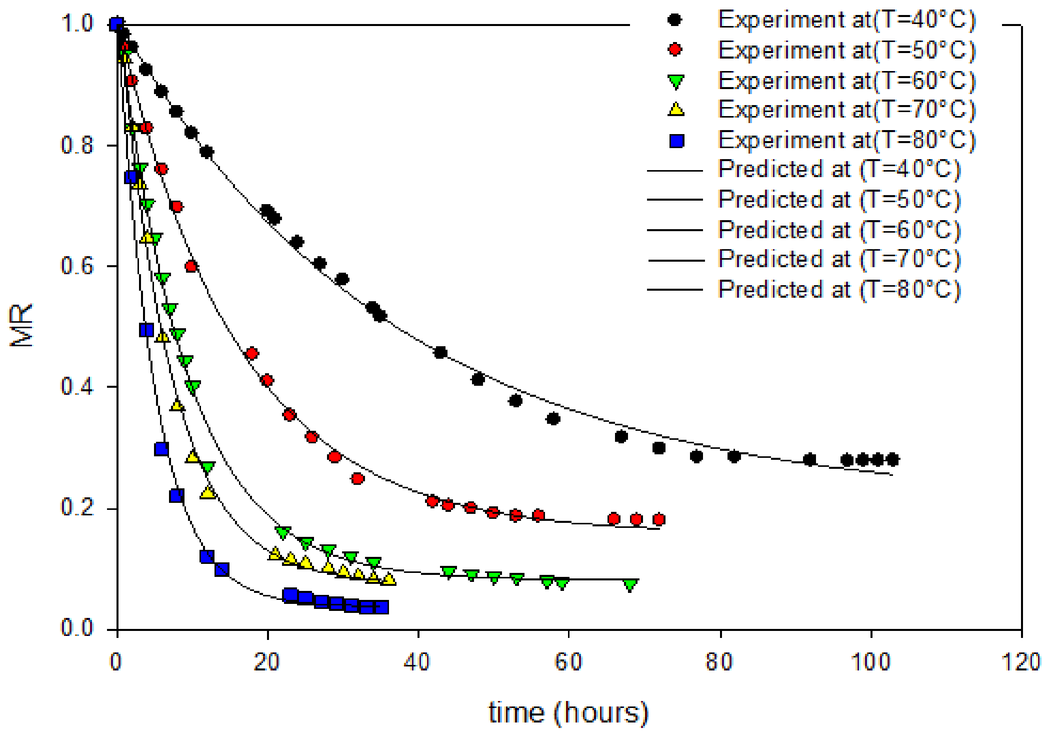

Figure 5: Experimental and predicted moisture ratio curves with drying time of ripe Kampong paddy under different drying temperatures with exponential decay (double, 3 parameters) model

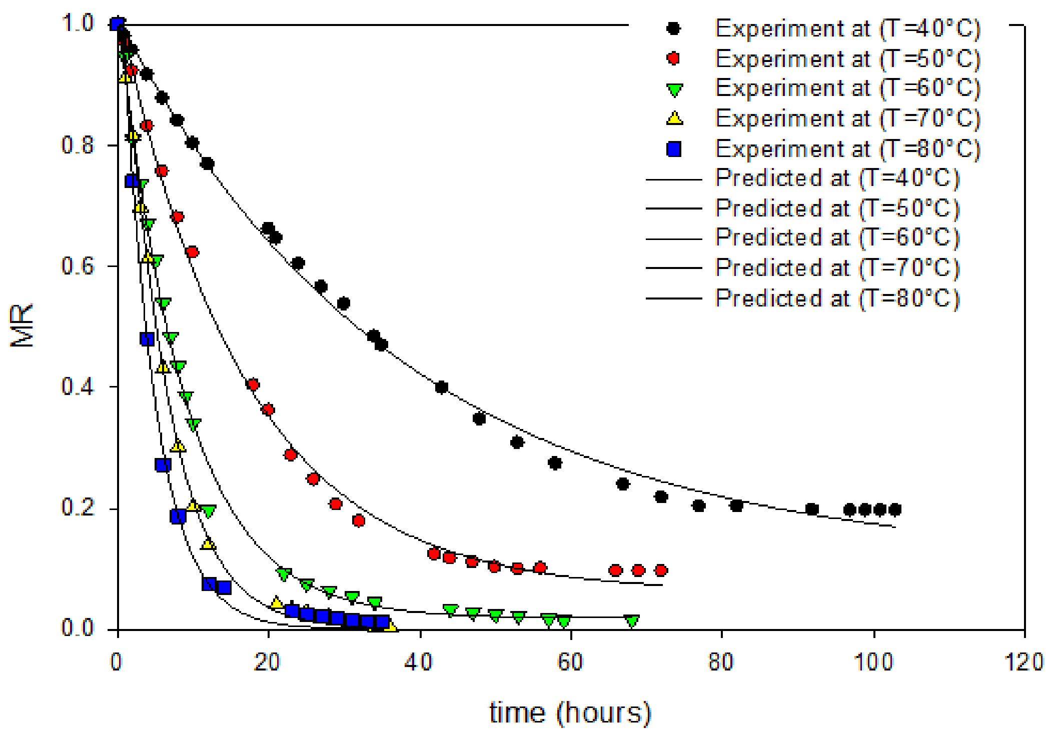

Figure 6: Experimental and predicted moisture ratio curves with drying time of unripe Kampong paddy under different drying temperatures with exponential decay (double, 4 parameters) model

Table1: Mathematical model from Sigma Plot 10 applied to drying curves of paddy

	Model Name	Model
1.	Exponential rise to max (single, 3 parameters)	$y = y_0 + a(1 - e^{-bx})$
2.	Hyperbola (single rectangular I, 3 parameters)	$y = y_0 + \frac{ax}{b + x}$
3.	Hyperbola (hyperbolic decay, 3 parameters)	$y = y_0 + \frac{ab}{b + x}$
4.	Exponential decay (single, 3 parameters)	$y = y_0 + ae^{-bx}$
5.	Exponential decay (double, 4 parameters)	$y = ae^{-bx} + ce^{-dx}$

Table 2: Statistical results of Sarawak Paddy drying models

	Temperature (°C)	y_0	a	b	c	d	R^2	χ^2	RMSE
Exponential rise to max (single, 3 parameters)	40	0.9987	-0.381	0.033			0.9943	9.82537E-05	4.37E-05
	50	1.0019	-0.4711	0.0593			0.9935	0.000194347	8.33E-05
	60	1.0032	-0.5665	0.1183			0.9963	0.000136768	5.98E-05
	70	1.0142	-0.6244	0.1486			0.9987	6.69107E-05	2.76E-05
	80	1.0054	-0.644	0.203			0.9975	0.000118338	4.65E-05
Hyperbola (singe rectangular I, 3 parameters)	40	1.0066	-0.4984	30.8496			0.9923	0.00035714	5.95E-05
	50	-0.5997	-0.5997	15.5488			0.9927	0.000218691	9.37E-05
	60	1.0275	-0.6785	6.6748			0.9932	0.000297839	0.000112
	70	1.0301	-0.7669	5.989			0.9935	0.000335473	0.000138
	80	1.0161	-0.7477	3.8039			0.9898	0.000473307	0.000186
Hyperbola (hyperbolic decay, 3 parameters)	40	0.5082	0.4984	30.8496			0.9923	0.000133928	5.95E-05
	50	0.4163	0.5997	15.5488			0.9927	0.000218691	9.37E-05
	60	0.349	0.6785	6.6748			0.9932	0.00025529	0.000112
	70	0.2632	0.7669	5.989			0.9935	0.000335473	0.000138
	80	0.2684	0.7477	3.8039			0.9898	0.000473307	0.000186
Exponential decay (single, 3 parameters)	40	0.6177	0.381	0.033			0.9943	9.82537E-05	4.37E-05
	50	0.5308	0.4711	0.0593			0.9935	0.000194347	8.33E-05
	60	0.4367	0.5665	0.1183			0.9963	0.000136768	5.98E-05
	70	0.3898	0.6244	0.1486			0.9987	6.69107E-05	2.76E-05
	80	0.3614	0.644	0.203			0.9975	0.000118338	4.65E-05
Exponential decay (double, 4 parameters)	40		0.381	3.30E-02	0.6177	5.60E-13	0.9943	0.000102526	4.37E-05
	50		0.4358	0.0659	0.5688	1.00E-03	0.9937	0.000200969	8.13E-05
	60		0.4781	0.0019	0.5309	0.1329	0.9975	9.9093E-05	4.13E-05
	70		0.6049	0.1555	0.411	0.0017	0.9988	6.81369E-05	2.61E-05
	80		0.3945	0.0031	0.6142	0.2209	0.9979	0.00010533	3.76E-05

Table 3: Statistical results of ripe Kampong paddy drying models

	Temperature (°C)	y_0	a	b	c	d	R^2	χ^2	RMSE
Exponential rise to max (single, 3 parameters)	40	1.01	-0.8026	0.0273			0.9969	0.000223126	9.96096E-05
	50	1.0128	-0.856	0.0628			0.9982	0.000164974	7.12386E-05
	60	1.0251	-0.9442	0.1088			0.9969	0.000327367	0.000143223
	70	1.0497	-0.9752	0.1433			0.9964	0.000462782	0.000190557
	80	1.0248	-0.9875	0.2007			0.9959	0.000446256	0.000175315
Hyperbola (singe rectangular I, 3 parameters)	40	1.0189	-1.0941	42.1109			0.9932	0.000496613	0.000221702
	50	1.034	-1.0824	14.7811			0.9914	0.000805911	0.000348007
	60	1.0572	-1.1367	7.6421			0.9877	0.001310943	0.000573538
	70	1.0666	-1.2029	6.5052			0.9868	0.001672787	0.000688795
	80	1.0342	-1.1436	3.9567			0.9807	0.00211771	0.000831957
Hyperbola (hyperbolic decay, 3 parameters)	40	-0.0752	1.0941	42.1109			0.9932	0.000496613	0.000221702
	50	-0.0484	1.0824	14.7811			0.9914	0.000805911	0.000348007
	60	-0.0795	1.1367	7.6421			0.9877	0.001310943	0.000573538
	70	-0.1363	1.2029	6.5052			0.9868	0.001672787	0.000688795
	80	-0.1095	1.1436	3.9567			0.9807	0.00211771	0.000831957
Exponential decay (single, 3 parameters)		0.2075	0.8026	0.0273			0.9969	0.000223126	9.96096E-05
		0.1568	0.856	0.0628			0.9982	0.000161934	6.99259E-05
		0.0809	0.9442	0.1088			0.9969	0.000327367	0.000143223
		0.0745	0.9752	0.1433			0.9964	0.000462782	0.000190557
		0.0373	0.9875	0.2007			0.9959	0.000446256	0.000175315
Exponential decay (double, 4 parameters)	40		0.8026	2.73E-02	0.2075	7.57E-13	0.9969	0.000232423	9.96096E-05
	50		0.856	6.28E-02	0.1568	7.26E-13	0.9982	0.000174139	7.12386E-05
	60		0.9438	1.09E-01	0.0814	0.0001	0.9969	0.00034406	0.000143358
	70		0.9752	1.43E-01	0.0745	4.23E-12	0.9964	0.000498381	0.000190557
	80		0.9875	0.2007	0.0373	1.63E-11	0.9959	0.000490882	0.000175315

Table 4: Statistical results of unripe Kampong paddy drying models

	Temperature (°C)	y_0	a	b	c	d	R^2	χ^2	RMSE
Exponential rise to max (single, 3 parameters)	40	1.0104	-0.8998	0.0265			0.9966	0.000309731	0.000138273
	50	1.0316	-0.9716	0.0601			0.9972	0.000333749	0.000144119
	60	1.0307	-1.0128	0.1146			0.9964	0.000433813	0.000189793
	70	1.0479	-1.0534	0.147			0.996	0.000585256	0.000240988
	80	1.0303	-1.0185	0.2061			0.9947	0.000619354	0.000243318
Hyperbola (singe rectangular I, 3 parameters)	40	1.0196	-1.234	43.9474			0.9928	0.000645656	0.000288239
	50	1.051	-1.2378	16.0383			0.9887	0.0013704	0.000591764
	60	1.0652	-1.2112	7.1299			0.9857	0.00172289	0.000753765
	70	1.066	-1.2936	6.282			0.9854	0.002160077	0.000889443
	80	1.0374	-1.1733	3.8335			0.976	0.002788179	0.001095356
Hyperbola (hyperbolic decay, 3 parameters)	40	-0.2144	1.234	43.9474			0.9928	0.000645656	0.000288239
	50	-0.1868	1.2378	16.0383			0.9887	0.0013704	0.000591764
	60	-0.1461	1.2112	7.1299			0.9857	0.00172289	7.17871E-05
	70	-0.2276	1.2936	6.282			0.9854	0.002160077	0.000889444
	80	-0.1359	1.1733	3.8335			0.976	0.002788179	0.001095356
Exponential decay (single, 3 parameters)	40	0.1106	0.8998	0.0265			0.9966	0.000309731	0.000138273
	50	0.0599	0.9716	0.0601			0.9972	0.000333749	0.000144119
	60	0.0179	1.0128	0.1146			0.9964	0.000433813	0.000189793
	70	-0.0055	1.0534	0.147			0.996	0.000585256	0.000240988
	80	0.0117	1.0185	0.2061			0.9947	0.000619354	0.000243318
Exponential decay (double, 4 parameters)	40		0.8998	2.65E-02	0.1106	1.56E-12	0.9966	0.000322637	0.000138273
	50		0.9716	0.0601	0.0599	2.12E-12	0.9972	0.000352291	0.000144119
	60		0.0179	3.59E-13	1.0128	1.15E-01	0.9964	0.000455504	0.000189793
	70		-0.2759	0.6198	1.2738	1.79E-01	0.9995	8.40854E-05	3.21503E-05
	80		-0.1691	451967.1	1.1691	2.28E-01	0.9973	0.000340659	0.000121664

CONCLUSION

This paper reported the correlation between drying temperature and drying rate for fragrant paddy in an oven. The drying rate of local varieties of paddy (Sarawak paddy, ripe local paddy and unripe local paddy) was strongly affected by the drying temperature. Furthermore, selected drying models were fitted to experimental data to determine the best model for describing the fragrant paddy drying profile. The highest R^2 and lowest χ^2 and RMSE were the main benchmark for selecting the best model. Results showed that the exponential decay (double, four parameters) model (two-term model) is suitable for drying Sarawak paddy and unripe Kampong paddy and that ripe Kampong paddy drying data fit the exponential decay (single, three parameters) drying model.

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