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Drying kinetics of mango fruit using tray and oven dryer

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Abstract

Drying is generally used to increase the shelf life of food products. In this context, mango fruit is used as a sample for the drying process because of its high commercial value and particularly high moisture content. The mango was sliced into few batches of sample with a size of 20 mm × 30 mm × 5 mm each. The experiments were conducted using tray and oven dryer at different temperatures of 40, 50 and 60 °C with a steady airflow rate of 1.3 m/s. The objectives are to study the effect of drying time, temperature and air velocity towards drying of mango fruit, to compare the physical characteristics of mango sample after drying and to determine the best drying kinetics model fitted to each tray and oven dryer. The results showed that the increase in drying time, temperature and air velocity would reduce the moisture content while at the same time, drying rate increased significantly. Tray dryer was found to be more effective than oven dryer because of higher drying rate with better product quality and appearance at the end. Furthermore, the gathered data were fitted into few widely used drying mathematical models and it was found that Henderson and Pabis model at 60°C is best suited for tray dryer whereas Page model at 40 °C is the best for oven dryer.

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1.0 Introduction

Mango fruit or scientifically called *Mangifera Indica* is well-known for its nutritional values and delicious taste. People around the world are attracted to its unique flavour, fragrance and taste which ultimately become important qualities for consumer's sensorial acceptance (Osman and Ramlan, 2015; Rosman et al., 2019). For these reasons, mango fruit is mainly consumed in its fresh form or as processed food such as juice, dried food, jam and others (Russo et al., 2019). Drying is usually done to preserve the fruit as many people like to eat dried fruit as a snack. Drying is the process of removing the moisture content of a food product for shelf-life elongation and microbial growth avoidance (Doymaz, 2014; Inyang et al., 2018; Morais et al., 2018). The removal of its moisture content involves the phenomenon of heat and mass transfer. Specifically, drying is said to go through the diffusion process on pore surfaces of the materials which includes liquid or vapour diffusion as there is a difference in moisture concentration (Inyang et al., 2018).

Wicking or known as capillary action occurs in granular and porous structures due to intermolecular forces between the liquid and solid surfaces (Inyang et al., 2018). The drying method is practically used until now for certain food products as it is economical and straightforward (Norhidayah et al., 2013; Shahari et al., 2016).

Various types of drying techniques have been used in the food industry, such as hot air drying, freeze-drying and vacuum drying (Ng et al., 2006; Rahman et al., 2012). Thin-layer drying principles are widely used to understand the fundamental of transport mechanisms (Inyang et al., 2018). Increase in drying time decreases the moisture content of the sample and simultaneously increases the drying rate. High temperatures would reduce the drying time and increase the drying rate. Air velocity also can influence the drying process in which the increased air velocity would decrease the moisture content of the sample as the drying and evaporation rate increase (Akoy, 2014; Shahari et al., 2015; Dereje and Abera, 2020).

Roughly, a thin-layer describes the condition of the samples that are sliced or cut thin according to the appropriate size used in an experiment. In an engineering context, many thin-layer drying models consist of different formulas. Therefore, the quantitative analysis can be compared to find the best model representing the relevant process (Khodiry et al., 2015).

Hence, these models can help in scaling up or optimizing the process and controlling the operating condition of a process (Afolabi et al., 2015) to remain economical and better quality of products. Thus, it is essential to determine the most suitable condition for drying.

Tray dryers were composed of more than one tray while oven only used one tray per time. The food will be spread out on the trays and heating medium (hot air) will pass through across them. All the trays must fit into the chamber, so there is no 'leaking' in air distribution. As the heating medium cross the trays, it will set off the conduction process from the heated trays or surfaces and continue to move uniformly. Uniform airflow distribution over the trays resulted in the drying process excellent efficiency, which ensures the desired moisture content of the product is achieved consistently.

The concept of oven dryer is similar to the tray dryer in which the sample is spread out on the tray but using radiation as its heating medium. It lacks an air velocity controller; thus, the air velocity cannot be controlled nor measured. The radiation application formed when power is supplied and triggered the source of radiation to serve the heating medium in the chambers (Rihana et al., 2019).

Moreover, it is used for low moisture content products to prevent overheating of the particles. This can happen if it is prolonged even at a temperature near 60°C and resulting in degradation quality of the material. The heat is transferred to the product by convection and water evaporation is also moved to the surrounding by convection way (Guiné, 2018; Rihana et al., 2019).

In this current study, tray and oven drying were used to achieve these objectives: (i) to study the effect of drying time, (ii) temperature and air velocity towards drying of mango fruit, to compare the characteristic of the sample after drying, and (iii) to determine the best drying kinetics model fitted to tray and oven dryers by calculation.

2.0 Methodology

2.1 Material

Ripe mangoes used in this experiment were purchased from a local supermarket in Shah Alam, Malaysia. It has an average weight of 250 g while the average weight of each sample was approximately 5 g, which was measured using an analytical balance. The mangoes were peeled, sliced, and kept in a plastic container before being brought to the laboratory. The sliced sample had an average size of 25 mm × 30 mm × 5 mm.

2.2 Experimental devices

Experimental devices used were laboratory-scale tray dryer (G.U.N.T. Hamburg CE 130), also known as cabinet dryer and a conventional oven (Misha et al., 2013). The tray dryer was composed of compartments for drying chambers, control panel, air heating system, and electrical supply. The drying chamber has 4 trays with 5 cm spacing between them. The trays have a 30 cm × 40 cm dimension by mean 12 m^2 as their surface area. The conventional oven (Memmert UF450) consists of a control panel, electrical supply, a drying chamber with one tray only, and a radiation heating system. The tray dimension is 20 cm × 30 cm resulted in the surface area of 6 m^2.

The weight loss of the sample was measured using an analytical balance (KERN 440-45N) with precision of ±0.1 g. The temperature probe and thermometer were used to measure the surface temperature of the product conditions. Anemometer (Extech AN300) was used to measure the drying air velocity as well as to determine the relative humidity. A stopwatch was used to measure the time set to record the required parameters. These parameters would be recorded every 15 minutes for the effect of drying time and 20 minutes for others.

2.3 Methods

2.3.1 Calibration curve

A calibration curve test was conducted before the drying experiment to ensure the precision and accuracy of the collected data. The main power was switched on, the fan and heater were turned on, then the power controller was set to Level 1. After 15 minutes, temperature data at Level 1 was collected.

Power was then set to Level 2 for 15 minutes to collect another temperature data. These steps were repeated until power of Level 7. Then, the calibration curve was plotted using temperature against the power level (Ismail et al., 2019).

2.3.2 Effect of drying time

The drying processes were conducted at a constant airflow rate of 1.3 m/s and were tested at temperatures 40, 50 and 60°C to investigate the effect of drying time on the weight loss of mango samples. The air velocity was regularly monitored using an anemometer to ensure that it is maintained at 1.3 m/s. The sliced mango samples were distributed uniformly on the tray and placed in the drying devices to dry. Weight losses of the samples were measured every 15 minutes for 3 hours. These steps were repeated at different temperatures. All experiments were done in triplicate to get more accurate data. The drying curve was plotted using the drying times against weight loss. The moisture content of the samples was calculated.

2.3.3 Effect of temperature

Careful measurements were taken to ensure that the mass of the sample must be constant in all tests and air velocity was maintained at 1.3 m/s. Tests were done at temperatures of 40, 45, 50, 55 and 60 °C. The sample was distributed evenly on the tray and placed into the devices. The sample weights were measured after 20 minutes of drying, and the weight losses were calculated. All tests were repeated three times for data accuracy. A curve was then plotted using temperature against weight loss to determine the effect of temperature towards the drying process of mango fruit.

2.3.4 Effect of air velocity

The temperature was held constant at 60°C while varying the air velocities at 0.5, 0.8, 1.0, 1.3 and 1.5 m/s to investigate the effect of air velocity to the drying of mango samples. Drying time was 20 minutes. A curve was plotted using air velocity against weight loss to determine the effect of air velocity towards the drying process of mango fruit.

2.3.5 Data analysis

All data obtained from experiments were analysed to obtain drying rate curve. The curve consists of moisture content as manipulated variable and time as the responding variable. The moisture content, X, of the sample can be calculated using Equation (1) where X can be described as the ratio of the weight of the water content to the weight of dry material. The dry basis is chosen for the calculation because the moisture content percentage is calculated relative to the dry weight of the sample. The graph of the moisture content versus drying time was plotted for each experiment.

$$X = \frac{X_o - X_f}{X_f} \tag{1}$$

where X = moisture content, X_o = initial moisture content and X_f = final moisture content.

From the moisture content value, the drying rate, V (min^{-1}), can be calculated using Eq. (2). The graph of drying rate versus moisture content was plotted for each experiment to describe the drying curves of this process.

$$V = \frac{X\,(t_1) - X\,(t_2)}{t_1 - t_2} \tag{2}$$

where V = drying rate, X = moisture content, t_1 = initial time and $t_2 = t_1 + \Delta t$

These obtained experimental data were then used to calculate the dimensionless moisture ratio (MR), which is required by the thin-layer drying models (Shahari and Hibberd, 2014). The data gained then were fitted into three models named Page, Logarithmic and, Henderson and Pabis models. The thin-layer drying models used are shown in Table 3, including the corresponding constants. The moisture ratio can be calculated using Eq. (3).

$$MR = \frac{X_t - X_e}{X_o - X_e} \tag{3}$$

where MR = moisture ratio, X_t = moisture content at any time, X_e = equilibrium moisture content and X_o = initial moisture content.

The correlation coefficient (R^2) and root mean square error ($RMSE$) are the criteria required to select the best model for this process (Shahari et al., 2014; Ismail et al., 2019). The highest R^2 and lowest $RMSE$ showed the best model to describe the drying curve and determine the fit's consistency. The higher the value of R^2 and the lower the value of $RMSE$, the better the accuracy of the fit (Chukwunonye et al., 2016; Hada Masayu et al., 2017). R^2 and $RMSE$ can be calculated using Eq. (4) and (5), respectively.

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}(MRexp - MRpre)^2}{\sum_{i=1}^{N}(MRexp - MRpre)}\right] \tag{4}$$

$$RMSE = [\frac{1}{N}\sum_{i=1}^{N}(MRexp - MRpre)]^{\frac{1}{2}} \quad (5)$$

where *MRexp* = experimental moisture ratio, *MRpre* = predicted moisture ratio and *N* = number of observations.

3.0 Results and discussion

3.1 Calibration curve

Calibration curves are necessary to check or ensure the precision of the system in a device. It also guarantees more accurate data would be obtained. The calibration curve of tray dryers has been plotted as shown in Fig. 1. The curve was plotted using temperature against the power level data. The data obtained are illustrated in the curve as well as the value R^2. The R^2 value achieved in the curve was 0.9982, which is considered very good as the values are close enough to 1.0. Thus, the device can be said to be in good condition and ready to be used.

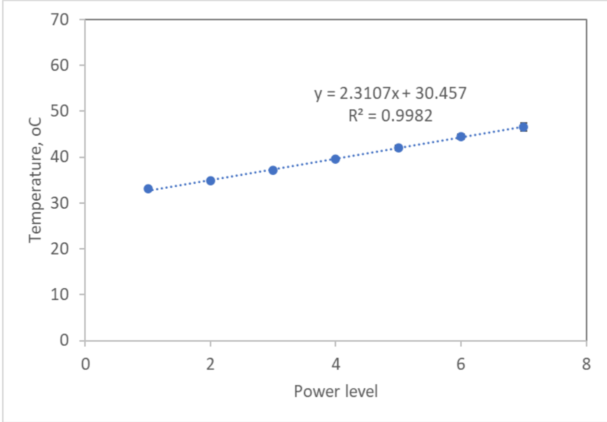

Fig. 1 Calibration curve for tray dryer

3.2 Effect of drying time

Based on the data of the effect of drying time, the moisture content was determined using Equation (1). After that, the drying curves of moisture content (%) against drying time (min) were plotted to illustrate the drying process of mango fruit.

The drying curve of mango in tray dryer and oven dryer is shown in Fig. 2 and Fig. 3, respectively. The sample was dried at a constant time, 180 minutes for both dryers at three different temperatures: 40, 50, and 60 °C.

The figures show that as the drying time increases, the moisture content of the sample decreases. The moisture content in the sample is diffused or evaporated to the drying medium existing in the dryers over time; thus, samples keep drying. This result is consistent with the previous work, which mentioned that increased temperature would decrease the moisture content of the used sample (Lewicki, 1998; Dissa et al., 2008; Akoy, 2014; Link et al., 2017).

Moreover, from the data obtained, the drying rate can be determined by calculation using Eq. (2). The drying rate pattern of the process in both dryers was obtained by plotting the graph of drying rate against drying time.

Fig. 4 and Fig. 5 show the curve of the drying rate against time at 40, 50 and 60 °C of the tray and oven dryer. Based on the figures, it indicated that as drying time increased, the drying rate also increased. This is due to the decrease in moisture content value of the sample over time. A comparison of results with previous studies shows that the results obtained in this experiment are acceptable as they stated that the moisture is always reducing while the drying rate decreases. Besides, if the condition is prolonged, the sample can achieve a 100% drying rate at different periods according to their temperatures (Akoy, 2014). If estimated, the sample at 60 °C will consume a shorter time to reach a 100% drying rate. However, the value of the drying rate of the oven dryer would be different from the tray dryer. This is probably because of the type of drying medium present in the dryers.

Drying time is not the only factor that should be considered to investigate the characteristic of the drying process. Continuous studies of the drying process must be done due to advancements in technology that keep growing and might induce something better in the future.

3.3 Effect of drying temperature

The data were obtained at five different temperatures with the constant weight of the sample, 20 minutes drying time, and air velocity of 1.3 m/s. Each trial was repeated three times. A relation is constructed between temperature and weight loss, giving the result as in Fig. 6.

The relation of weight loss with temperature and the effect of temperature in both dryers involved. The figure illustrated that increasing the temperature would increase the weight loss and drying rate of the sample. This is because, higher temperature would have provided or supplied more heat energy in the heat transfer process. Thus, more moisture content was reduced within 20 minutes at a higher temperature. This agrees with previous work that mentioned higher temperatures would increase the drying rate (Saadon et al., 2011). If the experiment continued over time, high

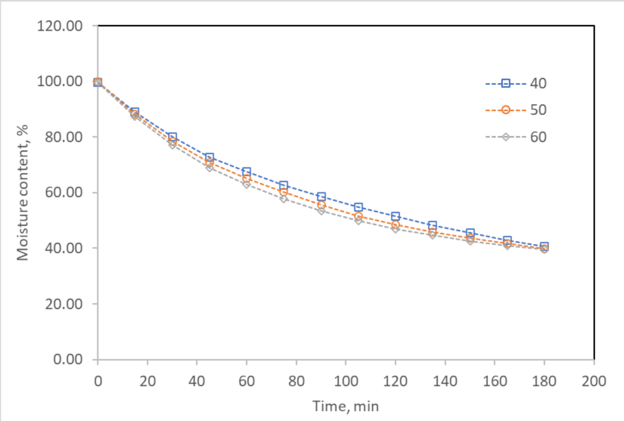

Fig. 2 Drying curve of mango in tray dryer

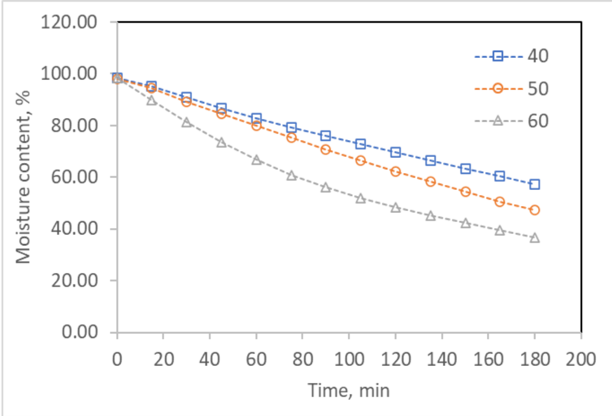

Fig. 3 Drying curve of mango in oven dryer

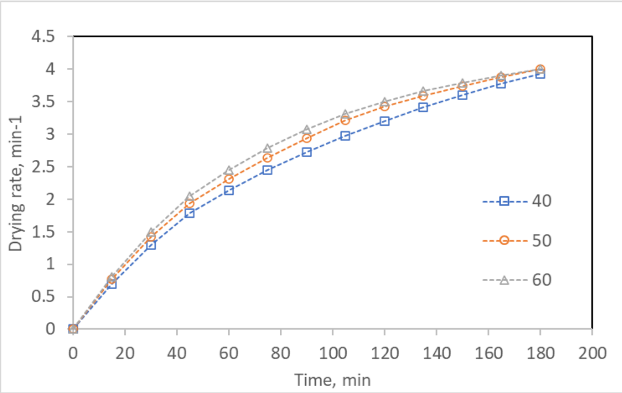

Fig. 4 Drying rate curve of mango in tray dryer

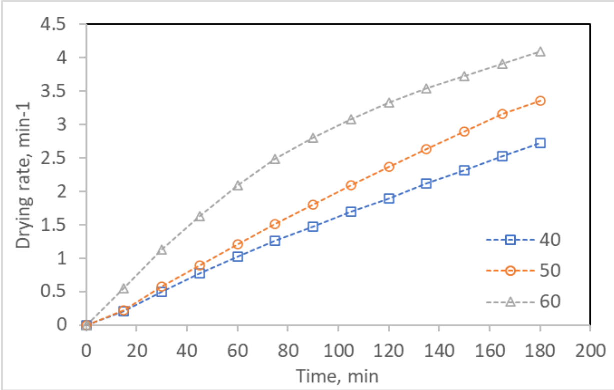

Fig. 5 Drying rate curve in oven dryer

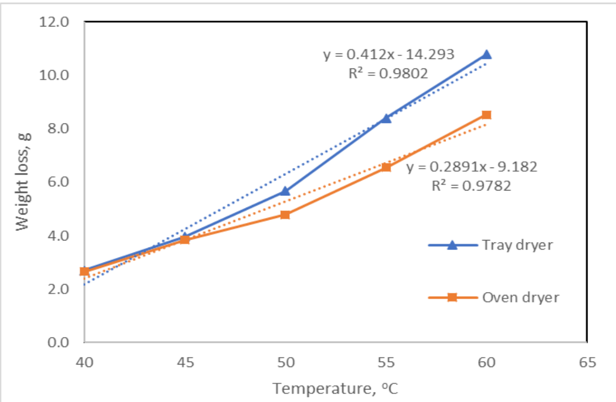

Fig. 6 Weight loss against temperature in tray dryer and oven dryer

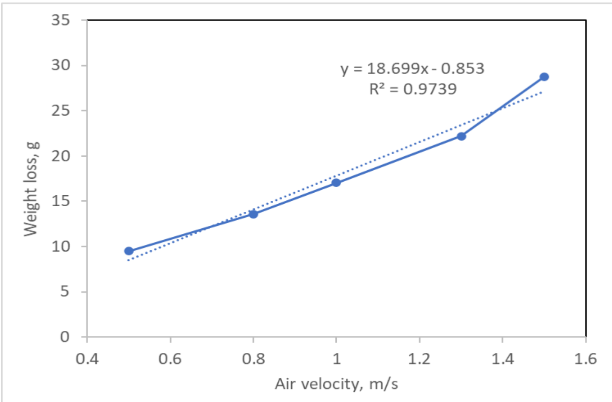

Fig. 7 Weight loss against air velocity in tray dryer

temperatures required a shorter time to dry the sample, resulting in a significant extension of drying capacity (Akoy, 2014). It can be concluded that the drying rate of the tray dryer is higher than the oven dryer. This matter could be because of the type of heating medium used, or efficiency of the heat transfer rate wherein the tray dryer is said to be transported uniformly through each tray. It is consistent with the results of the previous study that compared three types of dryers, including tray and oven dryers. The results concluded that the drying rate of the tray dryer was higher than the oven dryer, and it proposed a better efficiency (Rihana et al., 2019).

3.4 Effect of air velocity

The effect of air velocity is tested by exposing the sample to five different air velocities for 20 minutes each at which the mass of the sample is ensured to be constant. The air velocity is changed by controlling its button at the control panel and measured using the anemometer. In this context, it only involved the

Table 1: Characteristics of dried mango in tray dryer and oven dryer

Characteristic	Tray dryer		Oven dryer	
Colour	40 °C	Yellow (no change)	40 °C	Maintained yellow colour
	50 °C	Yellow (no change)	50 °C	Yellow but have slightly dark colour at the edges
	60 °C	Yellow (no change)	60 °C	Yellowish-brown as dark colour approach increases
Dryness	40 °C	Watery	40 °C	Watery
	50 °C	Dried slightly	50 °C	Quite dry with few watery structures
	60 °C	Dried with some watery structure	60 °C	Fully dried
Shrinkage	40 °C	No change	40 °C	Did not shrink
	50 °C	Slight shrink	50 °C	Slight shrink
	60 °C	Shrink slightly	60 °C	Shrinked and changed in size and shape
Smell	40 °C	Aromatic (no change)		Aromatic (no change)
	50 °C	Aromatic (no change)	50 °C	The smell changed
	60 °C	Changed slightly	60 °C	Slightly burnt smell

application of tray dryers. It has an open end, while oven dryers did not have the air velocity button and in closed containers; thus, air velocity cannot be measured using an anemometer. This experiment is repeated three times for a better result. The results are shown in Fig. 7.

An increase in air velocity would increase the rate of weight loss. This is because higher air velocity would increase the drying rate and accelerate the evaporation process, which in turn improve the elimination of moisture content in the sample. Thus, more weight loss obtained in high air velocity conditions over time. The result was consistent with the past study and it can be strongly justified that one of the studies also found that high air velocity aid in faster drying (Misha et al., 2013).

3.5 Product characteristics comparison

Observation of mango sample characteristics was done and recorded after the drying process. The characteristics mentioned are the colour of the product, dryness, shrinking rate and smell (Lewicki, 1998; Muhayyidin et al., 2019). These characteristics were compared between the tray and oven dryers with the initial sample at constant time and three temperatures, which were namely at 180 minutes and 40, 50, and 60 °C, respectively. Table 1 compares the characteristics of the products using different dryers.

It was found that the tray dryer successfully maintained the colour of the mango while the oven dryer showed the sign of getting burnt by having a slightly dark colour around the edges of the sample. It showed that overheating occurred if drying was prolonged at a temperature of about 60 °C and degraded the quality of the material. Furthermore, observation of both samples' dryness texture gave results that the sample in the tray dryer was not

Table 2: Equilibrium moisture content and ratio values

Temp. (°C)	Tray dryer			Oven dryer		
	Time at X_e (min)	X_e	*MR*	Time at X_e (min)	X_e	*MR*
40	180	40.57	0.4560	180	57.31	0.6415
50	180	39.79	0.4232	180	47.46	0.6250
60	180	39.49	0.3903	180	36.85	0.489

Table 3: Selected mathematical equation models (Inyang et al., 2018)

Models Name	Model Equation
Page	$MR = exp\ (-kt^n)$
Logarithmic	$MR = a\ exp\ (-kt) + c$
Henderson and Pabis	$MR = a\ exp\ (-kt)$

completely dry as some watery structure still exists in the mango. Otherwise, the sample in the oven dryer is almost dehydrated as no moisture structure detected (Zulkifli et al., 2012).

The sample in both dryers shrunk, but the oven dryer sample shrunk more when compared to the tray dryer. The size and shape of the sample changed as their moisture content faded away over time. The last criterion observed was the smell, which can only be experienced during the experiment period. The sample in the tray dryer did not encounter any burnt smell; however, the oven dryer's sample does have a little smell of burnt. The smell was probably coming from the part of the sample that has a slightly dark colour. Overall, the tray dryer is found to be better than the oven dryer as the quality of the sample is still acceptable. In contrast, in the oven dryer, it degraded the sample's quality and appearance only at 60 °C which is the highest temperature.

3.6 Drying kinetics model

The drying data obtained was converted to a dimensionless unit of moisture ratio (*MR*). Predicted moisture ratio was calculated using Eq. (3) and the notation required in the equation such as equilibrium moisture content, X_e, was determined using the drying curve for both dryer types, as previously shown in Fig. 2 and Fig. 3.

Equilibrium moisture content refers to the point where the moisture content was neither gaining nor losing the moisture or in simple words the point where the curve is getting constant. For consistency and to be sure on the completion of the drying process, the value of X_e is taken at 180 minutes and X_t at 60 minutes was used for calculation of *MR*. Hence, the value of X_e and corresponding calculated *MR* is tabulated in Table 2.

The moisture ratio decreases as temperature increases. It is affected by the value difference of the moisture content at a particular time. The predicted *MR* obtained then proceeded with the experimental *MR* calculation. Then, *RMSE* and R^2 were evaluated using Eq. (4) and (5), respectively. As the value obtained, the drying process's characteristics in the tray and oven dryer can be determined. For experimental *MR*, the value from mathematical kinetic models is used, and previously three model kinetics were chosen. Thus, the equations of these three models are listed in Table 3.

These equations have some constant parameters; kinetic parameter, k (min^{-1}), a, c and n are the empirical parameters (dimensionless) (Uribe et al., 2014). The parameter values are different according to their temperatures. As the temperatures were set to 40, 50 and 60 °C, the parameter values were listed based on those temperatures. Table 4 presents the estimated parameters of these models at the required condition.

With the information gathered, the *MR* was calculated using those three models. The calculated values of *MR*, R^2 and *RMSE* are shown in Table 5. A good model was decided according to the value of the correlation coefficient (R^2) and root means square error (*RMSE*). The higher the value of R^2 and the lower the value of *RMSE*, the more accurate the fit would be. The best fit model represents the mango drying process's behaviour as well for its control processes. As calculated in Table 5, the selected model is highlighted at a specific temperature. For the tray dryer, it shows that the best fit model is Henderson and Pabis model at 60 °C, while for the oven dryer, the best fit model is Page's model at 40 °C.

Table 4: Parameters of drying models according to temperature (Rayaguru and Routray, 2012)

Model name	**Temp. (°C)**	***k***	***a***	**c**	***n***
Page's	40	0.004	-	-	0.965
	50	0.005	-	-	0.939
	60	0.006	-	-	0.928
Logarithmic	40	0.003	0.997	- 0.021	-
	50	0.0032	1.018	- 0.0617	-
	60	0.0035	1.020	- 0.0651	-
Henderson & Pabis	40	0.0032	0.981	-	-
	50	0.0037	0.970	-	-
	60	0.004	0.967	-	-

Table 5: Modelling of moisture ratio, R^2 and RMSE values

Model	Temp. (°C)	Tray dryer			Oven dryer		
		MR	R^2	*RMSE*	*MR*	R^2	*RMSE*
Page's	40	0.5486	0.9074	0.1014	0.5486	0.9866	0.0385
	50	0.5191	0.9041	0.1032	0.5191	0.9071	0.1016
	60	0.4756	0.9147	0.0974	0.4756	0.8941	0.1085
Logarithmic	40	0.5689	0.8871	0.1120	0.5689	0.9274	0.0898
	50	0.5380	0.8852	0.1130	0.5380	0.9130	0.0983
	60	0.5090	0.8813	0.1148	0.5090	0.9800	0.0471
Henderson & Pabis	40	0.5515	0.9045	0.1030	0.5515	0.9100	0.1000
	50	0.4983	0.9196	0.0913	0.4983	0;8733	0.1186
	60	0.4707	0.9249	0.0910	0.4707	0.9817	0.0451

4.0 Conclusion

The drying process will always reduce the moisture content of a product over time. It was found that increasing drying time would decrease the moisture content and simultaneously increased the drying rate. Temperature and air velocity also affected the drying process as a high condition of these parameters would increase the rate of drying of mango fruit. A tray dryer is estimated to have a higher rate of drying compared to oven drying and said to be more efficient. In the comparison of mango characteristics, tray dryer successfully dried the sample without significant changes in its colour, size and smell while in oven dryer, the sample was observed to be slightly burnt indicated by dark colour appeared around the sample and its size shrinks a lot. It proposed to maintain product quality and appearance even after the drying process is done. Furthermore, the best kinetic models to represent drying of mango in tray dryer is Henderson and Pabis model at 60°C with R^2 and *RMSE* value of 0.9249 and 0.0910 respectively, Whereas for oven drying of mango, the best kinetic model is Page model at 40°C with R^2 and *RMSE* value of 0.9866 and 0.0385, respectively. These models obeyed the statement of having a higher value of R^2 and lower value of *RMSE*.

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