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Performance evaluation of a rotary dryer for onion bulb drying

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Abstract

Drying is conducive in extending the storage life of fresh harvested onion. Currently, direct sun drying is not suitable in terms of fluctuating weather conditions. Rotary dryer assisted by combustion heating is a viable option to speed up onion drying process. In this case, 10 kg of fresh onion was placed in a rotary dryer operating for 2 hrs at 40°C and 14.6 m/s of air velocity. Moisture content was observed at every 30 mins and drying rate was predicted using several mathematical models. The drying temperatures were 50, 60, 70°C and the drying procedures were repeated. Results showed that the rotary dryer method can improve drying performance compared to the chamber and tray dryer methods and the drying rate of onion bulb drying can be well represented by the Page's model with R^2 value near to 1, and the lowest average chi-square (X^2) of 0.00027.

1. Introduction

The number of imports continues to increase in line One of the agricultural products, the onion (*Allium cepa* L.), has various health benefits for people and is frequently utilized in both food and medicine (Djaeni and Arifin, 2017). According to USDA, the nutritional composition of raw onion contains water, protein, total lipid, ash, carbohydrates, total sugar, total dietary fibre, and important minerals such as potassium, calcium and selenium. Due to the bioactive components of onions, several epidemiological studies found that consuming it can reduce the chance of developing a number of diseases, including inflammatory, coronary heart, cancer and respiratory issues (Mota *et al*., 2010; Sami *et al.,* 2021).

Fresh onions have a high moisture content of about 83-92% (wb) and this could promote growth of bacteria, fungi and other micro-organisms. This is a challenge in the post-harvest processing to maintain product quality before consumption and marketing (Asiah *et al*., 2017; Beye *et al*., 2019). Drying is one of the post-harvest processing methods that can be used to decrease the product's moisture content and increase shelf life by reducing water activity, which prevents the growth of bacteria that can taint the items (Mujumdar and Law, 2010). Additionally, the dried onion also are lighter and smaller in size, which will make the subsequent handling and transportation tasks much easier before consumption (Kaveh *et al*., 2020).

The most common method of onion preservation used worldwide is sun drying. However, this method is dependent on daily fluctuations of weather and it could take longer drying duration and result in uneven product moisture content as well as the product being easily contaminated with airborne dirt and dust (Gouda and Nidoni, 2014). To minimize this, rotary dryer can be an alternative. As mentioned by Delele *et al.* (2015), the rotary dryer has several advantages, including being suitable for products of various shapes and sizes, as well as having high flexibility, allowing it to be used for a wide range of agricultural products, having high drying uniformity, and being easy to operate and maintain. Several factors that must be considered when using the rotary dryer are the physical properties of the product, drying variables and drying conditions (Jover and Alastruey, 2006).

There have recently been numerous studies on rotary drying behaviour of different agricultural products such as chillies (Kaleemullah and Kailappan, 2005), soybean (Luz *et al*., 2009), paddy (Firouzi *et al*., 2017), tobacco (Zhu *et al*., 2016) and peppermint (Tarhan *et al*., 2010). However, until now there has been no research on drying with the rotary dryer method on onions. The purposes of

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this research are to study the drying characteristics of onion bulbs using rotary drying and to develop a mathematical model for explaining moisture content reduction in onion.

2. Materials and methods

2.1 Sample and material preparation

Onion bulbs (*Allium cepa*) were harvested from farmers in Nganjuk, East Java, Indonesia (7°36'03.9"S 111°55'50.6"E) in 2021. Onion samples were stored in normal conditions until further research was carried out. Before the drying process, the onion bulbs were sprayed first with 1000 ml of water to equalize the water content, then onion bulbs were measured using the gravimetric method to obtain an initial moisture content value and obtained at 82.92-84.74%wb (Figure1). Rotary dryer, electric oven, digital scales, stopwatch, poly nets, RH gauge, anemometer and thermometer were also used for this research process.

2.2 Drying procedure

Approximately 10 kg of onion bulbs were dried in a rotary dryer for 2 hrs at 40, 50, 60 and 70°C with an air flow rate 14.6 m/s. Then the air temperature, relative humidity (RH), and moisture content of onion bulbs during drying were measured every 20 mins. Air temperature and relative humidity were measured using a temperature and humidity meter (Krisbow Indonesia, KW06-561). Meanwhile, the gravimetric method using an electric oven at 115°C for 24 hrs or until the onion mass was constant.

2.3 Determination of moisture content

The moisture content was determined using Eq. (1) (Mauer and Bradley, 2017):

$$MC_{db} = \frac{W_w - W_d}{W_d} \qquad (1)$$

Where is the moisture content in dry basis, is the wet weight of onion (kg), and is the dry weight of onion (kg). The dry weight of onion was obtained by drying the sample at temperature of 115°C in the oven until a constant weight achieved (Khramtsov *et al*., 2021; Tugnolo *et al.*, 2021).

2.4 Mathematics modelling of drying curve

The following equation can be used to calculate the moisture ratio (MR) of onion bulbs drying during experiments:

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

Where M_t denotes the moisture content (db), M_0 denotes the initial moisture content (db) at time 0, and M_e represents the equilibrium moisture content in dry basis (db) (Sasongko *et al*., 2020). The value of M_e was calculated using Modified Henderson equation (Asiah *et al*., 2017).

$$1 - H_R = exp[-A(T + C)M_e^B] \qquad (3)$$

Where H_R represents the relative humidity (RH), T is the drying temperature (°C) and A, B, and C are constants with values of 3.6×10^{-5}, 2.48, and 10.87 respectively (Sasongko *et al*., 2020).

Here it is assumed that only moisture in the outer layer of onion bulb evaporated. Thus, the Newton, Page, Modified Page, Logarithmic, and Henderson and Pabis (Ramachandra and Rao, 2009) were used to describe the moisture ratio in relation to drying time as follows (El-Beltagy *et al*., 2007; Tunde-Akintunde, 2011; Ademiluyi and Abowei, 2013):

Newton : $MR = exp(-kt)$ (4)

Page : $MR = exp(-kt^n)$ (5)

Modified Page : $MR = exp(-kt)^n$ (6)

Henderson and Pabis : $MR = a\,exp(-kt)$ (7)

Logarithmic : $MR = a\,exp(-kt) + c$ (8)

Where *t* is the drying time (min), *k* denotes the drying rate constant (1/min), and is a drying coefficient. T$_o$ select the best-fit model, the experimental results were evaluated using sum of square error (SSE) (Eq. 7), the root means square error (RMSE) (Eq. 8), and coefficient of determination (R^2).

$$SSE = \frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre.i} - MR_{exp.i}\right)^2 \qquad (9)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre.i} - MR_{exp.i}\right)^2} \qquad (10)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{exp,i} - \overline{MR}_{exp}\right)^2} \qquad (11)$$

$$X^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - Z} \qquad (12)$$

3. Results and discussion

3.1 Moisture content curve

The effect of temperature on the moisture content of drying onion bulbs was investigated in this study. Figure 1 shows the drying curve of onion bulb with various drying temperature at 40, 50, 60 and 70°C and an air velocity of 14.6 m/s for 2 hrs on wet basis moisture content. The results showed that increasing the air temperature can speed up the drying process by exposing the material pores and promoting moisture evaporation from the material (Sri Lestari *et al*., 2019). Also, at higher temperature, the movement of moisture content inside the onion becomes faster as more heat was absorbed, and more water was evaporated. Thus, can speed up moisture removal in onion.

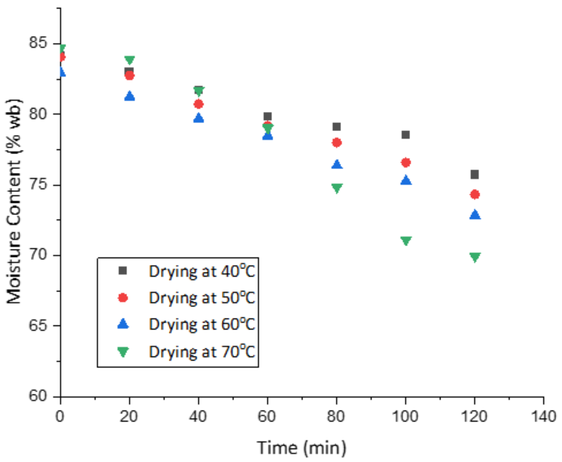

Figure 1. Moisture content (%wb) curve of onion bulbs at various drying temperatures with an air velocity of 14.6 m/s.

Drying onions using a rotary dryer method for 2 hrs at temperature 40, 50, 60 and 70°C sequentially can reduce the moisture content by 10.01, 11.57, 12.15 and 17.45%wb and product mass loss by 8.43%, 9.73%, 10.08% and 14.78% (Table 1). This value is different from drying onions using a chamber with automatic monitoring by Islam *et al.* (2019), when analyzing quality and modelling mass loss of onions during drying and storage, they mentioned that onion bulb which were dried for 14 days at 20°C experienced a mass loss of 3.7% and at 35°C experienced a mass loss of 4.7%. A different value was also found in the onion drying study conducted by A'yuni *et al.* (2022). In this study, onion bulbs which were dried using the tray dryer method for 2 hrs at 50°C and 70°C without dehumidification experienced moisture content loss of 0.3 and 1.21% wb, respectively. Based on a comparison of the three drying methods, drying onion bulbs using the rotary dryer method has a high drying rate so that it can speed up the process of reducing the moisture content of onion bulbs.

Table 1. The effect of drying temperature on the water content and mass loss onion bulbs

Temperature (°C)	Moisture content loss (%)	Mass loss (%)
40	10.01	8.43
50	11.57	9.73
60	12.15	10.08
70	17.45	14.78

3.2 Drying curves modelling

The five drying models namely Newton, Page, Modified Page, Logarithmic, and Henderson and Pabis models were used to describe the moisture ratio in relation to drying time. Table 2 shows the result of drying constants (k and b), drying coefficients (a and c), and statistical parameters (SSE, RMSE, R^2 and X^2). Based on the highest R^2 or close to 1, the lowest X^2, SSE, and RMSE value or close to 0, the best fitted model can be selected (Sahoo *et al.*, 2012).

The values of the coefficient of determination (R^2) in the Newton, Page, Modified Page, Logarithmic, and Henderson-Pabis models were (Table 2) 0.987, 0.991, 0.986, 0.987 and 0.989, respectively. In addition, the value of X^2 is sequentially 0.00061, 0.00027, 0.00061, 0.00046 and 0.00036. The average SSE for all models varies from 0.0019 for Page model and 0.0043 for Newton and Modified Page models. While the average

Table 2. The statistical parameters determined for the Page's model at various drying temperature.

Model	Temp (°C)	Model constants	SSE	RMSE	R^2	Mean R^2	X^2	Mean X^2
Newton	40	$k = 0.004$	0.0023	0.0485	0.982	0.987	0.00033	0.00061
	50	$k = 0.005$	0.0011	0.0336	0.994		0.00016	
	60	$k = 0.005$	0.0007	0.0265	0.996		0.00010	
	70	$k = 0.007$	0.0129	0.1134	0.976		0.00184	
Page	40	$k = 0.005; n = 0.957$	0.0476	0.0476	0.982	0.991	0.00032	0.00027
	50	$k = 0.007; n = 0.928$	0.0286	0.0286	0.995		0.00012	
	60	$k = 0.007; n = 0.941$	0.0225	0.0225	0.997		0.00007	
	70	$k = 0.002; n = 1.334$	0.0629	0.0629	0.989		0.00057	
Modified Page	40	$k = 0.006; n = 0.709$	0.0023	0.0485	0.982	0.986	0.00034	0.00061
	50	$k = 0.005; n = 0.967$	0.0011	0.0336	0.998		0.00016	
	60	$k = 0.006; n = 0.916$	0.0007	0.0265	0.998		0.00010	
	70	$k = 0.008; n = 0.942$	0.0129	0.1134	0.965		0.00184	
Henderson-Pabis	40	$k = 0.004; a = 0.997$	0.0023	0.0483	0.982	0.987	0.00033	0.00046
	50	$k = 0.005; a = 0.994$	0.0011	0.0326	0.993		0.00015	
	60	$k = 0.005; a = 0.992$	0.0006	0.0243	0.996		0.00009	
	70	$k = 0.008; a = 1.050$	0.0088	0.0941	0.975		0.00127	
Logarithmic	40	$k = 0.006; a = 0.821;$ $c = 0.180$	0.0023	0.0476	0.982	0.989	0.00033	0.00036
	50	$k = 0.008; a = 0.755;$ $c = 0.247$	0.0008	0.0276	0.995		0.00011	
	60	$k = 0.006; a = 0.893;$ $c = 0.102$	0.0006	0.0238	0.996		0.00008	
	70	$k = 0.003; a = 1.959;$ $c = -0.928$	0.0064	0.0799	0.982		0.00091	

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RMSE value for all models ranges from 0.040 to the Page model and 0.055 to the Newton and Modified Page models.

Hence, according to the results of the analysis of R^2, X^2, SSE and RMSE, Page's model is the best fitted to describe the thin-layer drying behaviour in the outer layer of onion bulbs and can be used for further application in onion bulb drying such as in prediction of drying time and moisture content, both in extrapolated and interpolated conditions. Figure 2 represents the experimental results and the Page model from onion bulb drying using a rotary dryer.

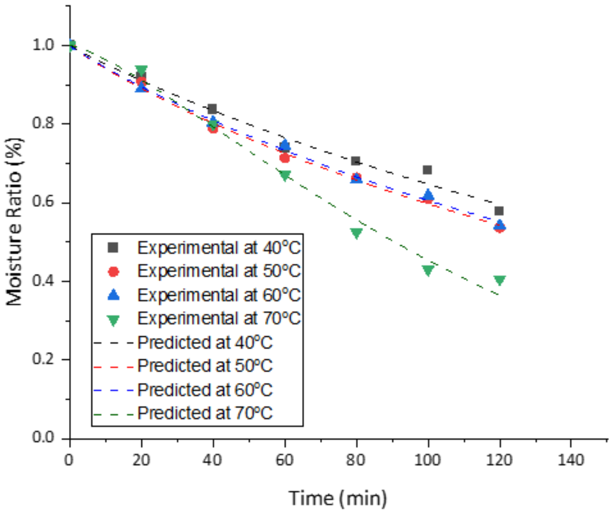

Figure 2. Comparison of experimental and predicted moisture ratios at various drying temperatures (Page's Model).

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, 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.

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