Jurnal Teknologi

Full paper

Drying Kinetics, Rehydration Characteristics and Sensory Evaluation of Microwave Vacuum and Convective Hot Air Dehydrated Jackfruit Bulbs

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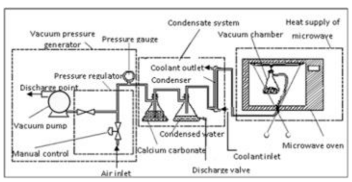
Article history

Received :11 July 2012
Received in revised form :
2 October 2013
Accepted :15 October 2013

Graphical abstract



Abstract

Microwave vacuum and convective hot air dehydration of jackfruit (Artocarpus Heterophyllus) bulbs were carried out to study the effects of different dehydration treatments on drying characteristics, rehydration ability and quality attributes. Jackfruit bulbs were dehydrated by microwave power output of 58, 140, 220, and 321W respectively combined with vacuum level of -65 cmHg during microwave vacuum dehydration. Convective hot air dehydration was also conducted with the hot air temperature of 60, 70, and 80°C, respectively. Microwave vacuum dehydration with microwave power output of 321 W resulted in 133 times faster in drying time compared to convective hot air dehydration with hot air temperature of 60°C. All dehydration data were subjected to Newton and Page's equation model fitting, where Page's equation model was well fitted for all dehydration conditions with $R^2 > 0.994$. Furthermore, microwave vacuum dehydration produced better quality of dehydrated jackfruit bulbs with higher rehydration ability and sensory attributes.

Keywords: Jackfruit; microwave vacuum dehydration; convective hot air dehydration; drying kinetics; sensory evaluation

Abstrak

Pengeringan nangka dengan menggunakan vakum gelombang mikro dan perolakan udara panas telah dijalankan untuk mengkaji kesan cara rawatan pengeringan tersebut terhadap ciri-ciri pengeringan, keupayaan terhidrasi dan kualitinya. Dalam pengeringan vakum gelombang mikro, nangka telah dikeringkan oleh kuasa gelombang mikro 58, 140, 220 dan 321 W masing-masing bergabung dengan tahap vakum -65 cmHg. Pengeringan perolakan udara panas juga telah dijalankan dengan menggunakan suhu udara 60, 70 dan 80 °C masing-masing. Pengeringan vakum gelombang mikro dengan kuasa 321W didapati 133 kali lebih cepat berbanding dengan pengeringan perolakan udara panas dengan suhu 60 °C. Semua data pengeringan telah dibandingkan dengan persamaan model Newton dan Page, data-data tersebut adalah sesuai dijelaskan dengan persamaan model Page dengan $R^2 > 0.994$. Selain itu, pengeringan vakum gelombang mikro menghasilkan kualiti nangka kering yang lebih baik, iaitu lebih tinggi keupayaan terhidrasi dan sifat-sifat deria.

Kata kunci: Nangka; pengeringan vakum gelombang mikro; pengeringan perolakan udara panas; kinetik pengeringan; penilaian secara deria

1.0 INTRODUCTION

Jackfruit (*Artocarpus Heterophyllus*) belongs to mulberry family. The yellow bulb-shape flesh, which is edible and covering the true seed, rich in vitamins A, B and C, potassium, calcium, iron, proteins, and carbohydrates. Malaysia is one of the major exporters of jackfruit in Asia. The export value was recorded about RM 9 million in 2003 [1]. However, jackfruit has short shelf life, only about three to ten days depending on the maturity, ambient temperature and relative humidity (RH) conditions [2]. This has been hindering the exportation market. Therefore, preservation is required to prolong the shelf life of jackfruit.

Dehydration or drying is one of the preservative methods to prolong the shelf life of jackfruit bulbs. During dehydration process, large portion of water content is removed from jackfruit bulbs. Hence, dehydration inhibits microorganism and enzymatic activities and avoids food damage and spoilage. Besides, due to the bulky size of whole jackfruit, the dehydration of edible jackfruit bulbs can reduce the size and weight up to 95%, which makes convenience for the handling, storage and transportation processes.

Convective hot air dehydration is the common technology applied to preserve agricultural produce. During conventional drying, heat energy transfer from surface of the material to the core while water content evaporates from the opposite direction. The drying process is considered slow as a result of low thermal conductivity of food materials. This exposes the food materials to high temperature for longer time, leads to degradation of nutrition and poor physical appearance [3].

Microwaves are electromagnetic waves generated by magnetron tube, with the frequency range from 300 MHz to 300 GHz. The application of microwave heating was initially employed since World War II. During microwave heating, water molecules as the dipole molecules in the food will rotate and align with electric field. Since microwave alternates its field too quickly, a phase difference exists between the rotation of water molecules and orientation of electric field. The phase difference creates random collision among the water molecules, causes energy loss and contributes to dielectric heating [4]. In addition, the penetration ability of microwave promotes volumetric heating. Thus, microwave provides fast and uniform heating throughout the entire food materials.

Microwave vacuum dehydration offers an alternative way to improve the quality of dehydrated food. Low pressure can reduce the boiling point of water to the level at where the effects of thermal degradation and discoloration are not significant [5]. Moreover, the absence of air during dehydration may prevent the process of oxidation. Numerous studies discussed the microwave vacuum dehydration process on different materials, such as mushroom, mint leaves and garlic [6-8].

Despite the wide study on drying characteristics of microwave vacuum and convective hot air dehydration of various agricultural products, no research has been published on the jackfruit. Therefore, the objectives of the present work were to: (i) investigate the drying characteristics of jackfruit bulbs by microwave vacuum and convective hot air dehydration; (ii) compare the quality attributes of the microwave vacuum and convective hot air dehydrated jackfruit bulbs in term of rehydration ability, colour, appearance and aroma.

■2.0 MATERIALS AND METHODS

2.1 Materials

Fresh jackfruit (cultivar J31) was obtained from a commercial farm in Pekan Nanas, Johor, Malaysia. The edible jackfruit bulbs were selected manually to obtain those in good condition and without deterioration. It was then followed by washing, peeling, cutting or pitting into halves. The initial moisture content of jackfruit bulbs was determined as 4.56 g/g dry basis.

2.2 Microwave Power Output Calibration

Microwave power output in the microwave oven was calibrated calorimetrically [9]. Microwave power output was determined by measuring the change of the temperature of a known mass of water (1000g) for a period of time, with the following equation:

$$Q\ abs = \frac{m\ Cp\ \Delta T}{t} \qquad \text{(Eq.1)}$$

The microwave energy was assumed totally absorbed by the water and no heat transfer to the surrounding. Heat capacity (Cp) of water was assumed independent of temperature.

2.3 Dehydration Procedures

The dehydration procedures were as follows:

(a) Microwave vacuum dehydration:

An experimental rig for microwave vacuum dehydration is shown in Figure 1. The microwave oven has four microwave modes, with the measured microwave power output viz. 58, 140, 220, and 321 W, respectively. 100 ± 0.5 g of jackfruit bulbs were placed in the vacuum chamber. Dehydration experiments were conducted with the four microwave modes, combined with constant pressure level of -65 cmHg. Weight of dehydrated jackfruit bulbs was recorded for every minute until final moisture content (0.1 g/g dry basis) was achieved.

(b) Convective hot air dehydration**:**

100±0.5 g of jackfruit bulbs were spread uniformly as a single layer on a tray in the cabinet dryer. The experiments were conducted with different hot air temperature of 60, 70, 80°C, with the constancy of other drying parameters (i.e. relative humidity, air velocity and direction). Weight of dehydrated jackfruit bulbs was recorded for every 30 minutes until the final moisture content (0.1 g/g dry basis) was obtained. All experiments of dehydration were triplicated and the average value was reported.

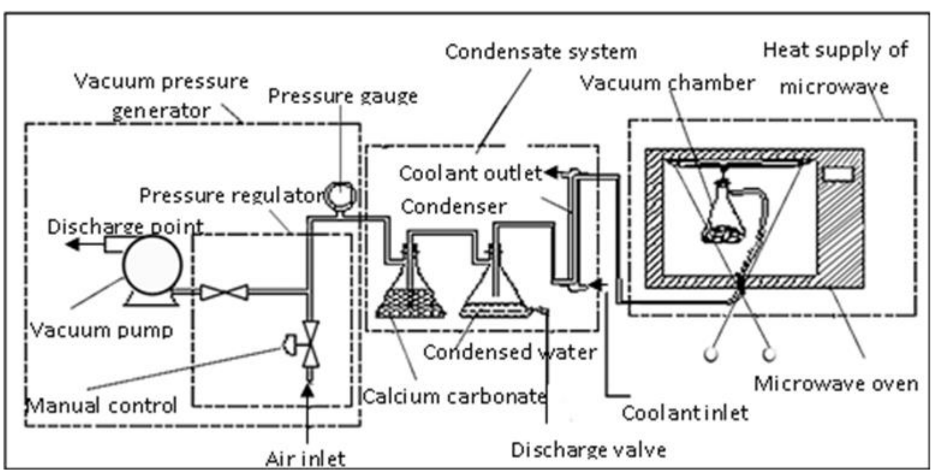


Figure 1 Schematic diagram of experimental rig for microwave vacuum dehydration

2.4 Empirical Model

The drying kinetics of jackfruit bulbs was predicted empirically by thin layer drying model namely Newton and Page's equation models. These models are described as follows:

Newton equation model: $MR = \frac{X-X_e}{X_0-X_e} = e^{(-kt)}$ (Eq.2)

Page's equation model: $MR = \frac{X-X_e}{X_0-X_e} = e^{(-kt^n)}$ (Eq.3)

where MR is normalized moisture ratio; X is moisture content in dry basis (d.b.); k is drying constant (min^{-1}); n is the dimensionless exponent; and subscripts 0 and e represent at time initial and equilibrium, respectively. The equilibrium moisture content X_e was assumed to be zero in microwave drying [10].

Non-linear regression analysis was performed using commercial software SPSS 15.0 to estimate the parameters k and n for both equations. Regression result were presented include the coefficients of the equations, together with coefficient of determination, R^2.

2.5 Rehydration Ability

A 5 g of dehydrated jackfruit bulbs was immersed in distilled water [6]. The sample was weighed for every 30 minutes until constant weight was obtained. Rehydration Ratio is defined as the ratio of the weight of rehydrated sample to the weight of dehydrated sample.

2.6 Sensory Evaluation

The sensory evaluation (colour, appearance and aroma) of dehydrated jackfruit bulbs was carried out by an untrained panel of 11 judges. For colour assessment, a colour bar (Figure 2) with the number range of 1 (dark brown) to 15 (light yellow) was prepared for the judges to indicate the colour of fresh and dehydrated jackfruit bulbs. Next, the appearance and aroma attributes were assessed in the preferable number range of 1 (dislike very much) to 9 (like very much) by using fresh jackfruit bulbs as the reference of 9 points.

Figure 2 Colour bar for sensory evaluation

2.7 Statistical Analysis

Three replications of each treatment were performed. Statistical analysis was conducted by analysis of variance (ANOVA) using commercialised software SPSS 15.0. Multiple comparison of means were carried out by Duncan's multiple range test at significant level of 0.05. One way analysis of variance was applied to find out if the differences in the mean values estimated were statistically significant [11].

■3.0 RESULTS AND DISCUSSION

3.1 Drying Characteristics during Microwave Vacuum Dehydration

The effect of different microwave power output on drying time of jackfruit bulbs was shown in Figure 3. Total drying time to dehydrate the jackfruit bulbs with microwave power output of 58, 140, 220, and 321 W with constant vacuum level of -65 kPa were 54, 21, 13, and 9 minutes, respectively. It was observed that higher microwave power output improved drying rate. The drying time with microwave power output of 321 W was reduced about 83% compared to low microwave power output of microwave vacuum dehydration. Higher microwave power output supplied more energy during dehydration, generated heat internally within the jackfruit bulbs due to dielectric properties. The rapid heating created more vapor within the jackfruit bulbs. The migration of interior moisture to the surface of material was accelerated due to total pressure gradient formed by the vapor. Moreover, lower water boiling point was achieved under vacuum condition, which facilitated the evaporation of water from jackfruit bulbs. Hence, fast drying occurred. Similar findings were reported by Alibas *et al.* and Karaaslan and Tuncer [12&13] on spinach drying and Soysal [10] on parsley drying.

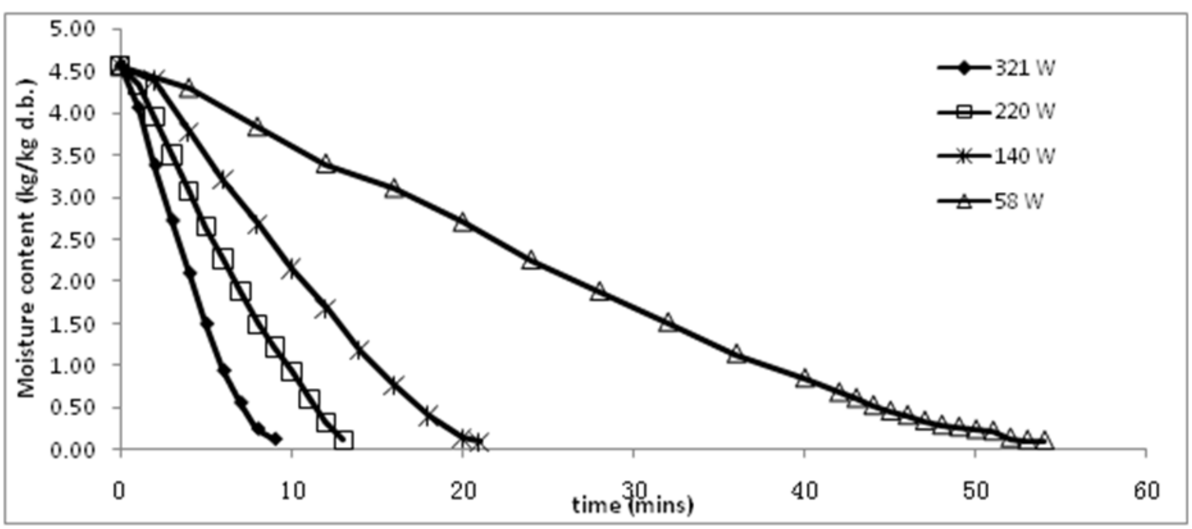


Figure 3 Effect of different microwave power output on drying time of jackfruit bulbs during microwave vacuum dehydration

Figure 4 shows the effect of moisture content on the drying rate of jackfruit bulbs during microwave vacuum dehydration. Since higher microwave power output exhibited shorter drying time, the drying rate of microwave power output of 321 W was the highest among the treatments. This result indicated the important effect of microwave power output on the drying rate.

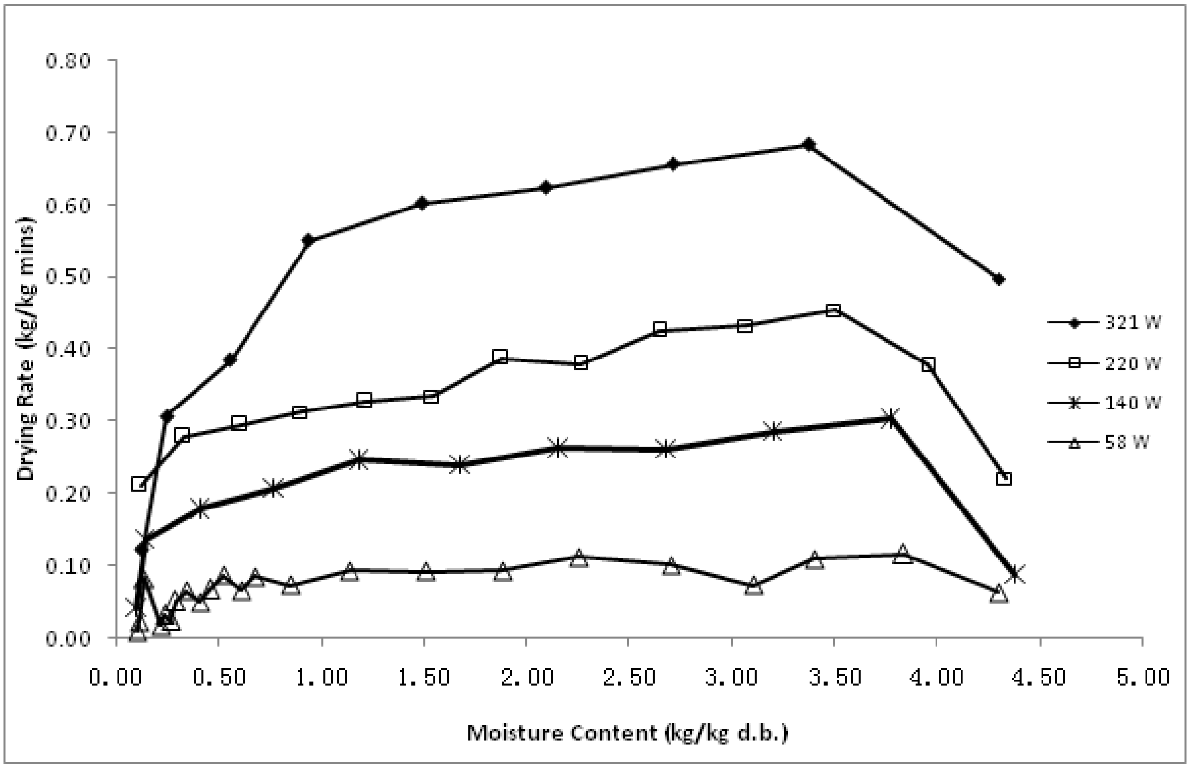


Figure 4 Effect of moisture content of jackfruit bulbs on the drying rate for different microwave output on microwave vacuum dehydration

Normally, two dehydration periods are found during drying process. Initially, constant rate period occurs when surface of the product is saturated with water. Therefore, moisture content on the wet surface evaporates at a constant rate. Later, the drying rate decreases progressively once the moisture content in the food no longer sufficient to saturate the whole surface. In this stage, falling rate period occurs.

In this research, microwave vacuum dehydrated jackfruit bulbs showed a long constant rate period during dehydration. This finding was in the agreement of Soysal and Ozbek and Dadali [10&14], who claimed a relatively long constant rate observed in the studies of parsley and mint leaves dehydration. After constant rate period, a decrease of drying rate was shown at lower moisture content (below 1.0 g/g dry basis). This may due to the reduction of dielectric properties in jackfruit bulbs. At the end of dehydration, moisture content remained in the jackfruit bulbs became less, attributed to low energy absorption. Thus, the drying process became slower.

3.2 Drying Characteristics during Hot Air Dehydration

Figure 5 shows the effect of different hot air temperature on drying time of jackfruit bulbs. Total drying time to dehydrate the jackfruit bulbs with hot air temperature of 60, 70, and 80ºC were 1200, 1100, and 720 minutes, respectively. The result showed that dehydration with hot air temperature of 60ºC was 133 times slower compared to the highest microwave power output of dehydration applied in this research. The low drying rate was attributed to the surface heating by convective hot air. According to Mujumdar [15], two processes will occur simultaneously when wet material subjected to thermal drying: first, transfer of energy from surrounding environment evaporates surface moisture and; second, internal moisture transfer from the material to surface and subsequently evaporate as happening in first process. Since mass transfer of conventional drying method is solely due to mass concentration gradient existing between wet interior and drier surface, thus this is always a slow process [16]. Besides, it was observed that more drying time was spent to reduce small amount of remained moisture in the dehydrated material during last stage of convective hot air dehydration.

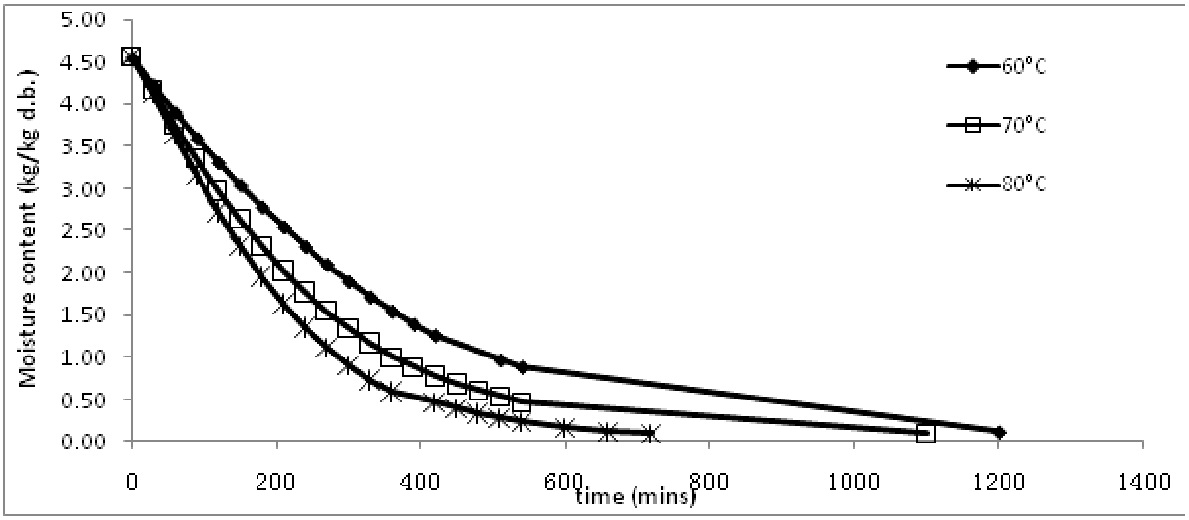


Figure 5 Effect of different hot air temperature on drying time of jackfruit bulbs during convective hot air dehydration

Figure 6 shows the effect of moisture content on the drying rate of dehydrated jackfruit bulbs during convective hot air dehydration. The drying rate of convective hot air dehydration was much lower compared to microwave vacuum dehydration. No constant rate period was observed during convective hot air dehydration of jackfruit bulbs. The altered result on the constant rate period obtained from both convective hot air and microwave vacuum dehydration may be attributed to their different dehydration mechanism. During microwave dehydration, dielectric properties of water molecules allow microwave generates heat internally within the jackfruit bulbs. This may promote the evaporation of internal moisture. The moisture will migrate continuously to the surface of jackfruit bulbs, causes the surface of jackfruit bulbs always in wet condition. Thus, constant rate period obtained. On the other hand, convective hot air dehydration supplies heat energy through convection, which will generate heat at outer surface of jackfruit bulbs. Subsequently, the energy will transfer layer to layer, reaching the inner part of jackfruit bulbs through conduction. Since this is a slow process, internal moisture content unable to saturate the whole surface of jackfruit bulbs and support constant evaporation. Thus, falling rate period occurred.

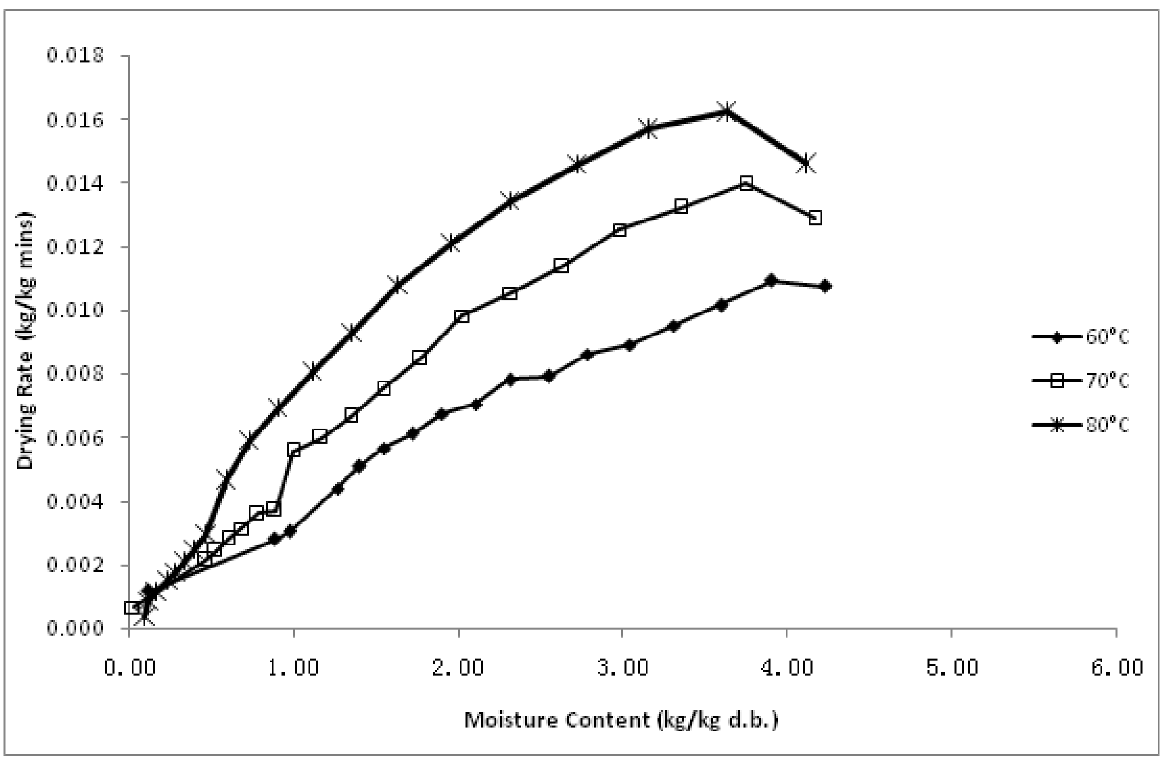


Figure 6 Effect of moisture content of jackfruit bulbs on the drying rate for different hot air temperature of convective hot air dehydration

3.3 Drying Constant

The drying constant, k and dimensionless exponent, n in Newton and Page's equation model for both microwave vacuum and convective hot air dehydration were estimated by non linear regression and the fitness is shown in Table 1. Page's equation model with an extra dimensionless exponent showed better fitting, especially for microwave vacuum dehydration (R^2 > 0.994). It was observed that the drying constant for microwave vacuum dehydration is higher compared to convective hot air dehydration. The drying constant in Page's equation model for microwave power output of 58, 140, 220 and 321 W during microwave vacuum dehydration were 0.003, 0.013, 0.040, and 0.089 min^{-1}, respectively. On the other hand, the drying constant of all convective hot air dehydration in this research are 0.002 min^{-1}. Drying with higher microwave power output contributed to higher value of drying constant, which agreed with Soysal and Alibas *et al*. [10, 11] on microwave dehydration of parsley and spinach.

Table 1 Non-linear regression analysis results of newton and page's equation model for microwave vacuum and convective hot air dehydration

Dehydration	**Newton**		**Page**		
	Drying rate constant (K), min^{-1}	**R^2**	**Drying rate constant (k), min^{-1}**	**Exponent (n)**	**R^2**
Microwave Vacuum Dehydration					
321 W	0.227	0.944	0.089	1.605	0.997
220 W	0.136	0.933	0.039	1.628	0.995
140 W	0.089	0.918	0.013	1.773	0.995
58W	0.040	0.924	0.003	1.724	0.994
Convective Hot Air Dehydration					
80 °C	0.005	0.991	0.002	1.194	0.999
70 °C	0.004	0.995	0.002	1.131	1.000
60 °C	0.003	0.997	0.002	1.101	1.000

3.4 Rehydration Ability

In most cases, rehydration ability is used as a measure of the damage to the material caused by dehydration. Figure 7 shows the rehydration ratio of microwave vacuum (58 W) and convective hot air (60°C) dehydrated jackfruit bulbs. In overall, the amount of moisture absorbed was increasing with the rehydration time, but the rate was slowing down when almost reaching the saturation level. The final rehydration ratio of microwave vacuum and convective hot air dehydrated jackfruit bulbs were recorded as 3.6 and 2.8, respectively. Besides, microwave vacuum dehydrated sample required only an hour to achieve saturation level but convective hot air dehydrated sample stabilized after three and half hours. Therefore, microwave vacuum dehydration showed better rehydration ability in this research. Similar finding was reported by Giri and Prasad [6] on mushrooms dehydration. The better rehydration ability of microwave vacuum dehydrated jackfruit bulbs may due to the higher porosity created by reduced pressure [17].

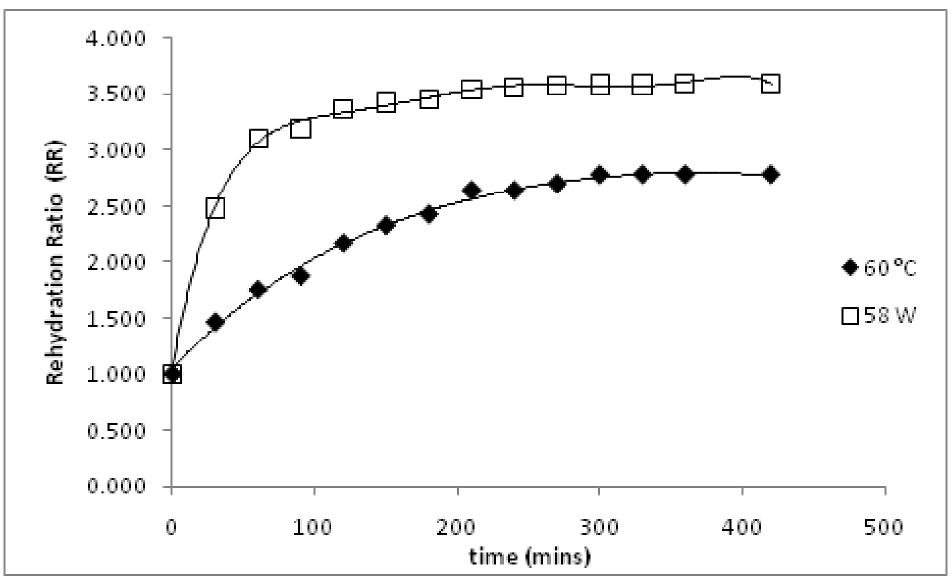


Figure 7 Rehydration rate of microwave vacuum and convective hot air dehydrated jackfruit bulbs

3.5 Sensory Evaluation

Table 2 shows the sensory score of colour for microwave vacuum and convective hot air dehydrated jackfruit bulbs, which were 13.5 ± 0.7 and 5.0 ± 1.4, respectively. The colour of microwave vacuum dehydrated jackfruit bulbs was almost similar compared with fresh jackfruit bulbs. In contrast, long drying time of convective hot air drying with high temperature exposure attributed to dark colour of the product, which resulted to the presence of brown pigments formed by Maillard non-enzymatic browning reaction. Hence, significant different of colour was observed in between convective hot air dehydrated and fresh jackfruit bulbs.

Table 2 Sensory score of colour for microwave vacuum and convective hot air dehydrated jackfruit bulbs

Samples	Colour Indicator
Microwave Vacuum Dehydration	
58 W	13.5 ± 0.7
Convective Hot Air Dehydration	
60 °C	5.0 ± 1.4
Fresh Jackfruit Bulbs (reference)	13.0 ± 0.8

Besides, microwave vacuum dehydrated jackfruit bulbs also showed better quality in term of appearances and aroma (Table 3). Fresh jackfruit bulbs was used as the reference of 9 points (like very much) during sensory evaluation. Microwave vacuum dehydrated jackfruit bulbs scored 7.7 ± 1.0 and 7.7 ± 0.6 for appearance and aroma, while convective hot air dehydrated jackfruit bulbs only obtained 3.4 ± 2.0 and 1.5 ± 0.7 accordingly. The higher scores of microwave vacuum dehydrated jackfruit bulbs may due to the reduction of drying time and pressure. Khraisheh *et al*. [18] observed that microwave dehydrated potatoes are less shrinkage compared with hot air dehydrated product. Raghavan and Koller [19] showed good aroma retention for microwave dehydrated rosemary.

Table 3 Sensory score of appearance and aroma for microwave vacuum and convective hot air dehydrated jackfruit bulbs

Samples	Appearance	Aroma
Microwave Vacuum Dehydration		
58W	7.7 ± 1.0	7.7 ± 0.6
Convective Hot Air Dehydration		
60°C	3.4 ± 2.0	1.5 ± 0.7
Fresh Jackfruit Bulbs (reference)	9.0	9.0

Note: Values are in form (mean ± standard deviation

■4.0 CONCLUSION

In this research, microwave vacuum dehydrated jackfruit bulbs save 133 times of drying time compared to convective hot air dehydration treatment. Page's equation model showed better data fitting to describe the drying characteristics of both microwave vacuum and convective hot air dehydration treatments, compared to Newton equation model. It was noted that higher microwave power output obtained higher value of drying constant among the microwave vacuum dehydration treatments. Results show that microwave vacuum dehydrated jackfruit bulbs obtained higher rehydration ability, scored higher in the sensory evaluation in term of colour, appearance and aroma attributes.

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