International Food Research Journal 23(Suppl): S163-S171 (December 2016)
Journal homepage: *http://www.ifrj.upm.edu.my*

Effect of raw material variation, process variables and device stability on drying process of rambutan (*Nephelium lappaceum* L.) seed

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Article history

Received: 20 June 2016
Received in revised form: 25 November 2016
Accepted: 26 November 2016

Keywords

Oven
Microwave
Rambutan seed
Drying time

Abstract

This study was conducted to determine the influence of raw material variation, equipment process variables and device stability on the drying process of rambutan seed using oven and microwave drying equipments. The raw material variations studied were skin colour (yellow and fully red), storage period (fresh and stored) and seed mass (5 and 10 g). The important equipment process variables studied were oven temperature (40 and 60°C) and microwave power (250 and 1000 W).The output power and drying distribution in the drying chamber were studied to examine the device stability. Results indicated that the seed mass, oven temperature and microwave power influenced the drying time. The skin colour and storage period were negatively correlated with drying time due to drying time speculate to relay on time required for moisture removal that associated to initial moisture content and seed mass. It is also observed that the drying time will be shorten if the sample was located at the central of the microwave drying chamber. In contrast, the oven exhibited higher stability compared to microwave due to its ability to provide similar level of heating at each location in the drying chamber. This information will aid researchers and industrial operators to design an effective drying process using microwave and oven thus reducing cost and time.

Introduction

A higher value of extracted crude fat from rambutan seed yielding between 37.1 - 38.9% compared to other local fruit seed is provide a promising potential usage of the rambutan seed (Augustin and Chua, 1988). Researches focusing on rambutan seed continuously increasing after it was declared as one of the industrial wastes that is significance in terms of waste amount (~ 4-9 g / 100g) (Sirisompong *et al*., 2011). The researches became more vibrant when the fat extracted can be broadly used in various fields ranging from food additives (Issara *et al*., 2014) to cosmetic (Lourith *et al*., 2016) and most recently it is scientifically acknowledged for its medicinal purposes (Soeng *et al*., 2015). Potential contributions in medicine became more prominent when the fat extracted that is highly rich in phytochemicals potentially inhibits α-glucosidase and glucose-6-phosphate dehydrogenase (G6PDH) activities that helps to lower triglyceride (TG) levels which can prevent obesity and all kinds of complications due to diabetes type 2 and cardiovascular disease. These results greatly favour the rambutan seed fat as potential to be anti-diabetic and anti-adipogenesis agent. Portrayed as non-toxicity substance to 3T3 - LI cells hence also acts as an alternative drug in addressing this global disease (Soeng *et al*., 2015). Transition of rambutan seed fat functions from food additives and cosmetics to other industrial uses is the main reason rambutan seed was used comparatively higher than other parts of the rambutan fruit. However, due to its seasonal nature their application in the industry and extensive research was limited. Thus, an effort to make it available throughout the year is deemed necessary. Therefore, the simplest, quickest and the most environmentally friendly pre-treatment used to prolong the life span of this agricultural crop is by way of drying.

Drying is the water removal process to achieve an equilibrium moisture level that is safe in microorganism multiplication and physiochemical degradation at a particular temperature and relative humidity (Hall, 1980). Drying is also a combination of mass and heat transfer processes which makes it a complex process. Insufficient or excessive exposure to the drying process will decrease the quality of a product. Thus, the ability to select suitable equipments and appropriate drying times necessary to produce an efficient drying process that can provide higher product quality remains unclear to the industrial

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operators. Therefore, the factors affecting the drying process must be determined in order to ensure the drying process applied is effective. Among the known factors that affect the drying process are mass, initial moisture content, temperature, air flow rate, shape and size (Geankoplis, 2003). However, the impact of drying variables on drying time is understudied, particularly for rambutan seed. Furthermore, recent trend in drying of rambutan seed pay particular attention to post - drying process (Chimplee and Klinkesorn, 2015; Rahman *et al*., 2015). Thus, an extensive research focusing upon the pre- drying process to determine the factors influencing the drying process is highly desired. To date, there has been no detailed investigation on the factors influenced in the drying process of rambutan (*Nephelium lappaceum* L.) seed. Previous drying equipments studied were mainly convective dryers, therefore, commonly used automatic electric oven and microwave dryer were chosen due to its potential to expedite drying process with increase product quality (Alibas, 2007). An extensive study on the drying variables such as raw material variation, process variables and device stability for these drying equipments will aid in the rambutan seed drying process.

Therefore, the aim of this study is to investigate the effects of raw material variation, process variables and device stability on the drying time using an electric oven and a microwave. The raw material variations involved are skin colour, the storage period, seed mass, while the process variables are microwave power and oven temperature. These act as the screening steps to enhance the drying process of rambutan seeds by having an efficient drying process. In addition, this study also aims to evaluate the stability of the equipment used in the drying process and to find out the actual level of efficiency of the appliances. The equipment limitation inherent in the drying process is also evaluated as it is believed the procedure was needed to rectify drying process problems. Hence, these research findings will provide a screening data to identify important factors in a drying process that can be fundamental to improve drying experimental design using oven and microwave equipment instead of directly focusing on the characterization and optimization to seek main effect, interaction and detection of curvature without further prior knowledge of these limitations. Therefore, a complete experimental design of drying process that involved screening, characterization, optimization, robustness and ruggedness testing will be offered. This fundamental data is needed especially during the design and scaling-up to industrial scale.

Materials and Methods

Plant material

Rambutan R4 clone was procured at Taman Pertanian Universiti (TPU), Universiti Putra Malaysia, Serdang, Selangor, Malaysia during two peak seasons on August to September 2015 and December 2015. Harvested fruit were sorted based on skin colour for uniform maturity. Sorted fruit were stored in polyethylene zip-lock plastic bag at 8.5°C in cool room prior to deseeding. Fruit were manually deseeded and washed seed were leaved for air-dried at room temperature to rid of the surface water surplus. Then, seed were stored in double polyethylene plastic zip-lock bag at 4°C in the chiller model Protech SD-700 (Advanced Scientific, Malaysia) prior to drying. Selected fruit for the drying process were within similar range of weight, length and width of fruit.

Initial moisture content

The initial moisture content of the rambutan seed was determined using an automatic electrical oven model OF-22GW (Jelotech, Korea), at 103 ± 2°C for 3 h until the weight loss less than 5 mg according to the standard methods for the analysis of oils, fats and derivatives of IUPAC 6th edition (Paquot, 1979).

Skin colour

Two types of skin colour have been studied, namely red and yellow. Measurements were only carried out upon the seed that had a similar range of initial moisture content and weight for bias control. Both types of seed were dried using automatic electric oven model OF-22GW (Jelotech, Korea) at 40°C and a microwave oven (Panasonic, Malaysia) at 250 W power level. Temperature used were normally applied in drying of agriculture crop (Chin *et al*., 2015; Fernandes *et al*., 2013). Whereas, 250 W microwave power was choose as it given comparable heating temperature to 40°C based on temperature measurement in microwave power output. All the samples were tested in triplicate.

Storage period

Fresh and stored seed for each skin colour; red and yellow respectively were compared. The stored seeds were kept in a refrigerator at 4°C for 7 days prior to drying while the fresh seeds were directly dried without being kept in a refrigerator first. The initial moisture content was measured for each seed groups before drying. The drying process was done in triplicate.

Seed mass

Two seeds mass, 5 and 10 g for each skin colour types were dried using a microwave oven (Panasonic Malaysia) at 250 W power in three repetitions.

Microwave power

5 g of rambutan seeds for each skin colour, of fresh and stored seeds were dried using a commercial microwave oven (Panasonic Malaysia) at two different power levels; 250 and 1000 W with three repetitions. Both power levels were equivalent to 40 to 60°C that normally applied in drying of agriculture crop based on temperature measurement in microwave power output (Chin *et al*., 2015).Weight loss was recorded at each 5 minutes interval for the entire drying process. These data were needed to plot the drying curve constructed from the values obtained from equation (1) and (2) as follows (Geankoplis, 2003);

Dry basis, X_t ;

$$X_t = \frac{W - W_s}{W_s} \quad (1)$$

Where;

W : weight of the wet solid in kg total water plus dry solid

W_s : weight of the dry solid in kg

Free moisture content, X ;

$$X = X_t - X^* \quad (2)$$

X^* : the equilibrium moisture content, kg equilibrium moisture/ kg dry solid (obtained directly from experimental data)

Oven temperature

5 g of rambutan seeds were dried using an automatic electric oven model OF-22GW (Jelotech, Korea) at two different temperatures, 40 and 60°C respectively. Drying was repeated in three replicates for each skin colour variety of fresh and stored seeds.

Microwave

There are certain limitation that need to consider in dealing with microwave such as non – uniform temperature distribution in drying chamber and overheating of the sample (Davis *et al*., 1997; Gürsoy *et al*., 2013). The available method with a slight modification has adopted in this study to assess the device stability (Cheng *et al*., 2006). A slight modification in handling output power determination was made in this study. For this study, the microwave output power was determined at each power that was programmed compared to previous that only determined at the highest power programmed. Criteria in broadening up the range of investigation is due to the need to identify the real efficiency for each program and also believed as a new contribution in the determination of the power output.

Microwave power output

The actual power produced by the microwave is observed via the absorbed microwave power calculated by equation 3 (Cheng *et al*., 2006). A 1000 ml of cool tap water was heated at the centre of microwave cavity for 3 minutes at full power. The initial and final temperatures were recorded using a digital thermometer model PDT 550 (UEI, USA) after 10 second stirring for uniformity. Heating was carried out at six different power levels according to available standard program in the commercial microwave at 1000W (P1), 270W (P2), 600W (P3), 440W (P4), 250W (P5), 100W (P6). Readings were taken with three replicates for each power level.

$$P_{ab} = \frac{CpWs\Delta T}{t} \quad (3)$$

Where,

P_{ab} = absorbed microwave power by water (watt, W)

C_p = capacity of water (4.18 J g^{-1} °C^{-1})

W_s = sample weight (g)

ΔT = temperature difference (°C)

t = time (s)

Distribution of microwave field inside cavity

The optimum power absorbed point in microwave drying cavity was determined by measuring percentage of power absorbed (Equation 4) at six key points on the surface of the ceramic tray as shown in Figure 1. The optimum point was determined by the percentage of the power absorbed (Cheng *et al*., 2006);

$$P_{ab}\,(\%) = \frac{Pab}{\Sigma Pab} \times 100 \quad (4)$$

where,

P_{ab} = absorbed microwave power by water (watt, W)

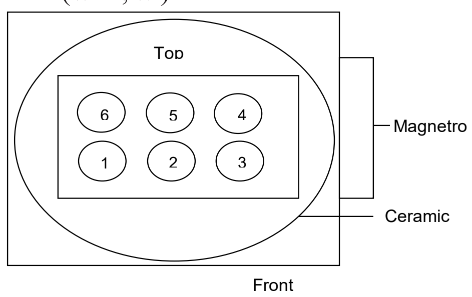


Figure 1.Top view of six key points on the surface of the ceramic tray

Optimum drying location

200 ml of cool tap water were scattered in five different locations at two tray levels (upper and bottom) as shown in Figure 2 in order to determine the optimum drying location. The sample was heated for 3 minutes at three different temperatures, namely 40, 50 and 60°C with three repetitions. The calculation applied for optimal drying location in oven was similarly as in microwave. Therefore, both equations 3 and 4 were adopted to calculate an optimum drying location in oven. Temperatures before and after heated were recorded after ten seconds stirred.

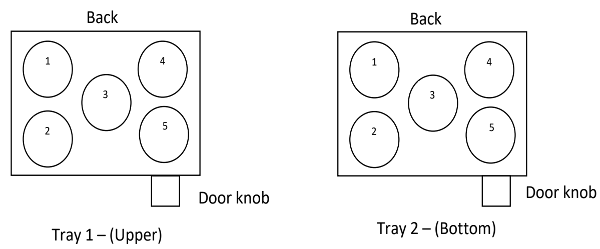


Figure 2.Top view on five scattered point for both upper and bottom tray in oven drying chamber

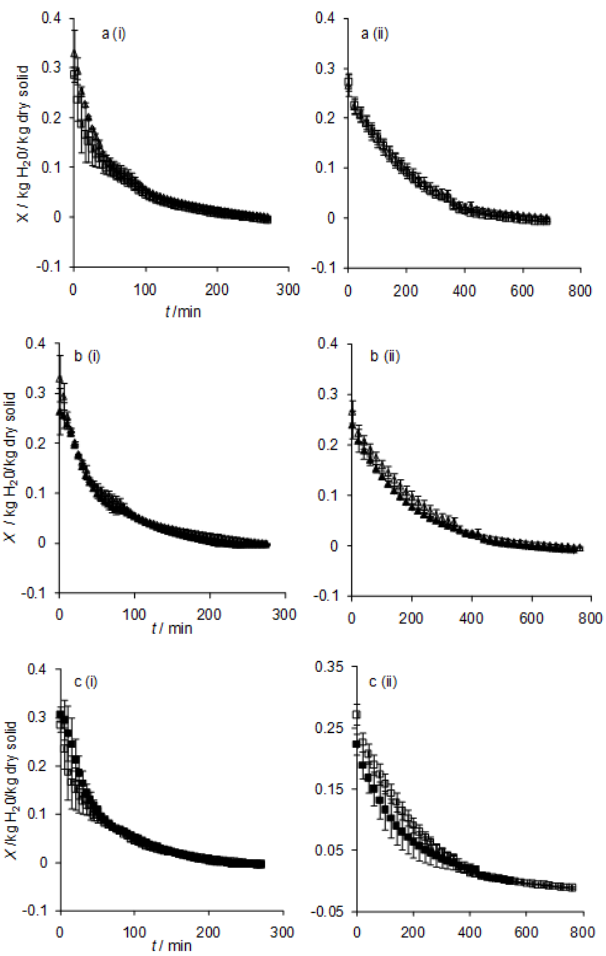
Results and Discussion

The performance and effectiveness of a drying process was measured in terms of the drying time. This is because previous researchers have consensus that the drying time is closely related to energy consumption, production cost and product quality (Senadeera *et al*., 2003; Clary *et al*., 2007; Tunku *et al*., 2015). Therefore, a shorter drying time is desired to ensure the effectiveness of the drying process that offers a higher product quality, energy saving and cost effective. Drying time refers to the total time required by a substance to remove the free moisture from the surface and moving the bound water within material to the surface for evaporation process until the moisture level of material and its surrounding achieved equilibrium in moisture content. The equilibrium moisture content is achieved when no noticeably changes in weight, even drying process constantly continued at a specific temperature and a relative humidity. This situation indicates that the final moisture content is attained and the product may not be affected by any changes in terms of chemical and microbiological as a continual exposed to temperature and relative humidity that has been set up (Tang and Yang, 2004).

Effect skin colour

There is no significant difference between the rambutan seed obtained from yellow and red skin in terms of the drying time, therefore accepting the null hypothesis where the rambutan skin colours do not affect the drying time. This can be observed based upon the poor correlation between the skin colour and drying time of 0.3260 and insignificant P value of 0.237 through one-way ANOVA. Another observation of the insignificant difference between the skin colour and drying time is depicted by a similar trend of the drying curves illustrated in Figure 3 for both drying equipments. This is consistent with other studies and suggest that drying time are normally affected by the initial moisture content, shape, size and drying properties such as air flow rate, relative humidity and temperature and is not influenced by skin colour variety that normally distinguished via colour as long as the previous listed parameter are analogous (Tang and Yang, 2004).

In terms of drying equipment, microwave oven had shorter drying times than electric oven (Figure 3). It is clear from Figure 3a (i) that only 270 minutes were required to dry for both skin colour of rambutan seed completely by microwave in comparison to more than 680 minutes of drying time (Figure 3a (ii)) needed when using an electric oven. This result can be explained by considering the different drying mechanisms involved during drying using microwave and electric oven.



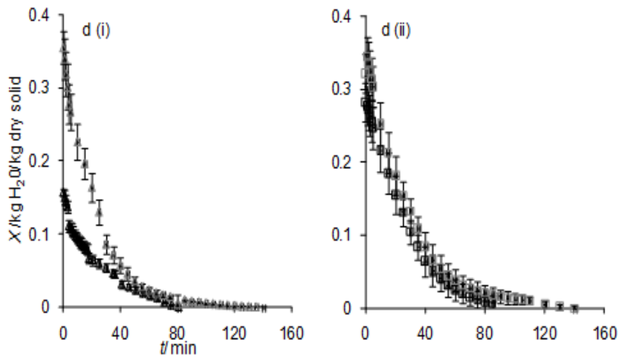


Figure 3. Drying curve of rambutan seed

(a) (i) Drying curve for both fruit colour varieties of rambutan seed under microwave drying ; (Δ) red fresh ; (□) yellow fresh

(ii) Drying curve for both fruit colour varieties of rambutan seed under automatic electric oven ; (Δ) red fresh ; (□) yellow fresh

(b) (i) Drying curve for fully red skin rambutan seed at two different storage period using commercial microwave oven; (Δ) red fresh; (▲) red stored

(ii) Drying curve for fully red skin rambutan seed at two different storage period using automatic electric oven; (Δ) red fresh; (▲) red stored

(c) (i) Drying curve for yellow skin rambutan seed at two different storage period using commercial microwave oven (□) yellow fresh; (■) yellow stored

(ii) Drying curve for yellow skin rambutan seed at two different storage period using automatic electric oven; (□) yellow fresh; (■) yellow stored

(d) (i) Drying curve for fully red skin rambutan seed at two different seed mass using microwave oven; (Δ) 5 g; (Δ) 10g

(ii) Drying curve for yellow skin rambutan seed at two different seed mass using microwave oven; (□) 5g; (□) 10 g

Drying in the microwave oven begins when the electric ions generated in the drying chamber supplied in accordance to the frequency capacity were fully absorbed by material. As a result, ions absorption will activate intra-particle movement within material. These movements generate attraction between particles and promote vibrations. These vibrations produce heat and at the same time increasing the temperature of the material and thus, accelerating water removal from inside to the surface for evaporation and help shortened the drying time required.

In contrast to earlier mechanism in microwave drying, the drying process in an electric oven, occurred when the thermal energy of the drying equipment increases the material temperature up to its wet - bulb temperature to allow the effective free water removal on the material surface that often reflected as constant rate period phenomena which is represented by a sharp short vertical line in the drying curve and none of this line distinctively found in Figure 3 and Figure 4.

After all the free water is removed, then the bound water in the material will take place. The bound water removal within material occurred when material temperature increase from wet - bulb temperature to dry- bulb temperature of the air. The bound water removal process from inside to the surface of the material is known as the falling rate period phenomena which is represented by a gradual decrease in the free moisture content, *X*, with time, starting from approximately five minutes of drying time (Figure 3 and 4). The drying process in the falling rate period took a relatively period of time. This can be considered to be due to two major processes involved in this stage; starting by demolishing the bound water bonding to become free water and allowing water particle to move to the surface for evaporation. Therefore, the drying process using the electric oven requires a longer drying time as it needs to stabilize drying air temperature for constant rate period taken place before risen up the material temperature to dry-bulb temperature, for allowing the drying process by falling rate period to occur (Tang and Yang, 2004).

This finding has important implications in broaden the sampling range of rambutan seed which is not limited to only one type of skin colour variety. This finding may facilitate future researchers in their sample preparation and thus, overcoming the limitations of previous problems due to diversity in fruit variety and maturity which are interpreted by their colour. The expansion of the usability of rambutan seeds irrespective of its skin colour can promote greater utilization and flexibility of rambutan seed drying process.

Effect of storage period

The current study found that the effect of storage period on the drying time was not statistically significant as shown by an insignificant P value of 0.122 (one-way ANOVA) and a poor correlation (R^2) of 0.3134. The insignificant effects of the storage period and the drying time was also exhibited through Figure 3b (i) and 3b (ii) where a nearly similar trend of drying curves were obtained for both fresh and stored rambutan seeds. In addition, there was no significant differences in terms of drying time required found between fresh and stored of rambutan seed for both variety of skin colour. This finding is beneficial where future studies can capitalise on the storage of rambutan seeds obtained during rambutan harvesting seasons. The utilization of rambutan seeds thus can not limited to only fresh seeds but also seeds that had been stored up to 7 days or could be more as long as the percentage of initial moisture is still in the range. No has been conducted on relationship between storage period of rambutan seeds and their drying times, it is likely that this new finding will encourage more researches on rambutan seed storage.

In accordance with the electric oven drying, microwave drying also demonstrated similar trend of drying curves as illustrated in Figures 3b and 3c. However, the microwave drying exhibited shorter drying times than the when using the electric oven. This is also in accordance with the earlier observation for the effect of skin colour, where the concept of heating used and the mechanism in bringing moisture from the material to the surface for the purpose of drying affected the drying time even if the level of the heating temperature is at the same temperature of 40°C.

Effect of seed mass

This study demonstrates significant difference effects of seed mass on the drying time. Significant differences of the seed mass on the drying time were presented by both a P value less than 0.05 (two-way ANOVA) and P value 0.002 (one- way ANOVA). Significant differences for the seed mass in this study corroborates to earlier findings that suggested drying times were only affected by mass, initial moisture content, shape, size and drying properties such as air flow rate, relative humidity and temperature (Geankoplis, 2003). This is most probably due to a higher seed mass will contain more moisture needed to be removed thus; a longer drying time was needed. A similar trend for the drying curves for both seed masses where a twofold increase in the drying time needed was observed when the seed mass was doubled (Figure 3d). This finding has important implication for developing relationship between seed mass and drying time that will aid future researches involving with rambutan seed drying utilizing variable seed masses.

Effect of microwave power

It was observed that higher microwave power levels lead to shorter drying times. This can be seen clearly in Figure 4a (i) and 4a (ii) as a lower power needed nearly 300 minutes to complete the drying process compared to less than 150 minutes at higher power. Microwave power significantly affected the drying time with a significant P value less than 0.05 and showed relatively good and strong correlation 0.9695 (one-way ANOVA). This finding rejected the null hypothesis that microwave power will not affect the drying time. At a higher power level, the microwaves intensity produced was higher and this further accelerated the bound water movement to the surface leading to a shorter drying time needed in falling rate period. There were no apparent constant rate periods i.e. no clear vertical straight line present in the drying curves for both Figures 4a(i) and 4a(ii) thus, it can be suggested that the drying time was solely due to the falling rate period. This finding will provide a procedure on the selection of microwave power particularly for those involved with commercial microwave oven techniques in order to optimize the process and thus promote a higher product quality.

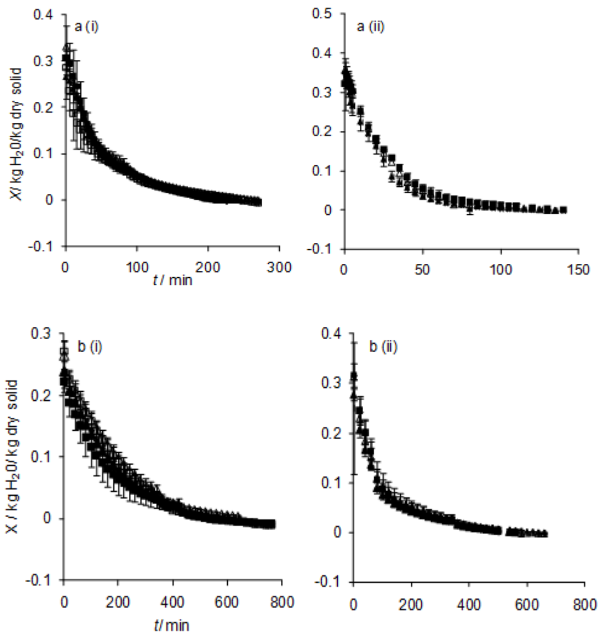


Figure 4 Drying curve of rambutan seed

(a) (i) Drying curve for both fruit colour varieties and storage period of rambutan seed at 250 watt using commercial microwave oven (Δ) red fresh; (▲) red stored; (□) yellow fresh; (■) yellow stored

(ii) Drying curve for both fruit colour varieties and storage period of rambutan seed at 1000 watt using commercial microwave oven (Δ) red fresh; (▲) red stored; (□) yellow fresh; (■) yellow stored

(b) (i) Drying curve for both fruit colour varieties of rambutan seed at 40°C using automatic electric oven (Δ) red fresh; (▲) red stored; (□) yellow fresh; (■) yellow stored

(ii) Drying curve for both fruit colour varieties of rambutan seed at 60oC using automatic electric oven (Δ) red fresh; (▲) red stored; (□) yellow fresh; (■) yellow stored

Effect of oven temperature

Figures 4b (i) and 4b (ii) illustrate the effects of oven temperatures on the drying times. Higher temperatures shorten the drying times at similar seed masses for both skin colour varieties and different storage periods. When the temperature increased by 20°C, the drying time improved up to 12.5%, where the drying time decreased from approximately 640 min to approximately 560 min for red fresh rambutan seed when other variables were kept constant (Figures 4b (i) and 4b (ii)). Temperature also significantly affected the drying time given by a low P value of less than 0.05 (one-way ANOVA). A high temperature will accelerate the process of vaporization occurring in the material hence promoting a faster water removal leading to a shorter drying time to achieve the equilibrium moisture content.

In the case of comparing the two types of equipments, at similar seed mass, microwaves exhibited a shorter drying time compared to oven. This result most probably due to the fact that different heating techniques were utilized for both of these equipments; electromagnetic wave and convection techniques. These findings will benefit researchers by providing better understanding of these two equipments.

Effect of device stability on drying time

The stability and efficiency of the equipment is the main factor in determining the effectiveness of the drying process, especially in comparing two different equipments in terms of the drying time. The equipment stability becomes more important if the combine or hybrid technique is applied in order to enhance the drying technologies (Cheng *et al*., 2006).

Microwave

As several previous study declared inconsistency of temperature distribution in microwave drying chamber as producing hot and cold spot alternately during the drying process (Davis *et al*., 1997), thus the test on the optimal drying location in oven cavity was conducted to ensure that the subsequent drying process was done at the same point of drying in order to ensure the uniformity in terms of total power absorbed and subsequently produce a reliable and reproducible experimental data. In addition, the analysis on the overall power output was also carried out on the microwave used to draw the limitation in this study as well as to represent the real efficiency of the microwave before the next drying process is carried out (Tang and Yang, 2004).

Microwave power output

Determination of the actual power produced by the microwave drying equipment is necessary to ensure the reliability and accuracy of the experimental data obtained, thus, the real microwave efficiency presented will define the equipment limitations when used for future research involving drying. It is important as the rate of commercial microwave efficiency is inversely proportional to its usage. Therefore, the optimum utilization of microwave would provide a minimum level of efficiency. Detailed data on this experiment were presented by two methods, which were based on the actual power generated and the percentage of power absorption by microwave.

The results show that the efficiency of each program was in the range of an average value of 71.13 to 140.06%. If the output power in this study was determined according to previous research (Cheng *et al*., 2006); where the microwave power output was determined based on its maximum power; thus, efficiency of this commercial microwave oven was 71.13%. However, in this study, the actual power was determined for each program, thus, it is found that program 3 became the best efficiency program with 94.9% actual power. A note of caution is due here since programs that gave percentages exceed 100% does not mean that it was very efficient. It might be related to the inconsistencies of the microwave power output. This result is consistent with previous study that suggest an actual microwave power should be determined before conducting the drying process using microwaves in order to find out the actual power level generated by the microwave, where the real efficiency of a microwave that can be used to gauge the limitations of the equipment used (Cheng *et al*., 2006).

Table 1. Percentage power absorption of microwave

Power level (W)	Percentage of absorbed power (%)			
	1st	2nd	3rd	Average
P 1 - 1000	69.67	71.98	71.75	71.13
P 2- 270	116.90	110.90	110.90	112.90
P 3- 600	94.80	96.70	93.20	94.90
P 4- 440	112.90	127.20	104.50	114.87
P 5 - 250	119.80	119.80	116.10	118.57
P 6 - 100	139.30	141.60	139.30	140.07

It can be clearly seen that all the programs listed that exceeded 100% efficiency recorded by the programs with less than 500 watts of power (less than half of full power capacity) and as the power level decreased, the efficiency increased up to 140.06% (Table 1). This result may be explained by the fact that the determination of actual power was carried out continuously program by program and as the program increased, the power setting was decreased. Hence, in the last program sequence at 100 W power level, when the magnetron had been operating continuously, this might be an extra heating space originating from a previous power supplied to cause even a slight but enough, to raised the temperature to exceed the temperature that should be given by the power 100 W and thus made the efficiency exceeded 100% due to the determination of the power generated was determined by the temperature differences between before and after heating.

One of the important issues emerging from these findings is that in order to determine the actual power generated by the program sequence, the power factor needed to be considered as the lowest power must be at the starting point and increase to the highest power if it is done continuously. However, if the power changes are done intermittently, a certain time interval must be given between the power changing (or program change) to ensure that the temperature recorded is based on the actual programmed power. Therefore, the determination of the power generated at low power less than 500 watts in this study would not be used and hence the percentage of efficiency for this microwave equipment was 71.13%.

It is recommended to run just one drying program at a time, but, if it needs to be run two slots drying program, the time interval between the two programs must be sufficient to ensure that the sample temperature to be at the room temperature before starting the next drying program that utilizes a different power program.

Distribution of microwave field inside cavity

Heating process via electromagnetic field normally led to non-uniformity warm-up. Therefore, in order to ensure the uniformity during the drying process, the initial data relating to the location that provides the optimal heating point must be determined. From the studies conducted, point 2 and 5 at the centre of the ceramic surface have received more power absorption rates for each program that were tested ranging from 18.70 to 20.01% and 19.04 to 19.62% respectively compared to 14.46 to 16.20% at different location. Therefore, it is recommended to use only these two points or locations inside the microwave drying chambers for use in the subsequent drying process to ensure the data obtained are reliable, uniform and accurate for each test performed.

Optimum drying location

Oven is equipment that is commonly used in the drying process for a variety of materials such as ceramic, pharmaceutical, food and agro-based materials. The diversity in the use of these equipments is clearly shown by its stability during the drying process. However, as to prove that it was really stable and there was no difference between the heating rates at the different locations inside the oven drying chamber, a test was conducted in order to determine the optimum drying location. Results indicated that there was no more than 1°C differences in temperature detected at different locations inside the oven drying chamber. Therefore, for future researches using the automatic electric oven, researchers can maximize the use of drying space inside the oven drying chamber due to its good heating uniformity and therefore be more cost effective.

Conclusion

Based on the data obtained, the drying process, seed mass, oven temperature and microwave power will affect the drying time. The fruit colour varieties and the storage period have no significant effects on the drying time. These findings will facilitate the researcher in carrying out their drying research using automatic electric oven and microwave oven. The use of microwave in drying process can reduce the drying time. Through this study, it is also found that automatic electric oven offered a higher equipment stability as it is able to provide the similar level of heating for each location in the drying chamber where this is not possible to be obtained by the microwave oven. Thus, this information is expected to be beneficial for researchers to conduct future research on drying particularly, involving with optimizing the drying process by combining both oven and microwave for shorter drying times and higher product quality. This combination of hybrid technique is highly desired as an effort to improve existing techniques for the drying process to be more cost effective as well as yielding a better quality product.

Acknowledgement

The authors are grateful to Universiti Putra Malaysia (UPM) for financial support via IPS research grant (vote no. 9464600) for the study. So’bah Ahmad is also grateful to UiTM for providing her the scholarship for her study.

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