Effective moisture diffusivity and activation energy of rambutan seed under different drying methods to promote storage stability

So'bah Ahmad[1a], Mohd Shamsul Anuar[1b], Farah Saleena Taip[1c], Rosnah Shamsudin[1d], Siti Roha A.M[2]

[1]Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor
[2]Food Technology Programme, School of Industrial Technology, Faculty of Applied Sciences, UiTM 40450 Shah Alam, Selangor

Email: mshamsul@upm.edu.my

Abstract. The effects of two drying methods, oven and microwave drying on the effective moisture diffusivity and activation energy of rambutan seed were studied. Effective moisture diffusivity and activation energy are the main indicators used for moisture movement within the material. Hence, it is beneficial to determine an appropriate drying method to attain a final moisture content of rambutan seed that potentially could be used as secondary sources in the industry. An appropriate final moisture content will provide better storage stability that can extend the lifespan of the rambutan seed. The rambutan seeds were dried with two drying methods (oven and microwave) at two level of the process variables (oven temperature; 40ºC and 60ºC and microwave power; 250W and 1000W) at constant initial moisture contents. The result showed that a higher value of effective moisture diffusivity and less activation energy were observed in microwave drying compared to oven drying. This finding portrays microwave drying expedites the moisture removal to achieve the required final moisture content and the most appropriate drying method for longer storage stability for rambutan seed. With respect to the process variables; higher oven temperatures and lower microwave powers also exhibit similar trends. Hopefully, this study would provide a baseline data to determine an appropriate drying method for longer storage period for turning waste to by-products.

1. Introduction

An increasing number of world hunger is mainly due to 40-50% in food loss and food waste and in turn, has led to a dire requirement in drying process improvement. Drying process needs as a tool for prolonging the lifespan of food waste that is believed to have potential to be used as an alternative food resource (FAO, 2015). Food loss expresses as a food source degradation in term of quality and quantity due to the production process. While food waste is a non-food product that has the potential to be used in another industry. Though, sourced that could be defined as food loss and food waste must be from agriculture and fisheries bases. The importance of the food waste as the main subject to be studied, due to its ability to reduce the hunger percentage via providing a sustainable resource in the food system, remain in the eco-nature environment and foster in nutritional food as well as food security (FAO, 2015).

The simplest process in converting food waste to by-product that could be used to industry and further realization of all diversifying functions of food waste is drying. Drying is moisture removal process to avoid microorganism multiplication that could lead in shifting the chemical and physical structure of the material (Geankoplis, 2003). This process is seen vital for food waste that is seasonal in nature such as rambutan seed as the subject in this study.

Rambutan seed used as the subject in this study due to its diversity functions as an alternative to cocoa butter in chocolate manufacturing (Issara, Zzaman, & Yang, 2014), potential fat extracted as cosmetics (Lourith, Kanlayavattanakul, Mongkonpaibool, Butsaratrakool, & Chinmuang, 2016) as well as beneficial for medicinal purposes where rambutan seed extract has the potential to react as αglycosidase which helps to reduce the risk sugar forming in blood (Sylvia Soeng et al., 2015). In addition, the balanced content of carbohydrates, protein, fiber, vitamins, minerals and fatty acids that are needed in the body cause its potential as a functional food product as Rambuseed Florentine (Hussin, 2015). Furthermore, the rambutan seed has been used as a snack food among the people of Java, Indonesia since ancient time. Hence, food waste classification could probably consider depending on cultural and lifestyle of the origin country. However, the various cultural and lifestyle have an advantage in developing research mainly on rambutan seed. This is because based on the unique dieting of rambutan seed as it is reliably high in nutrients content and effectively reducing the increase of glucose in blood among the Indonesians has led to ongoing research to prove through scientific finding (Slyvia Soeng, Evacuasiany, Widowati, & Fauziah, 2015; Sylvia Soeng et al., 2015; Solís-Fuentes, Camey-Ortíz, Hernández-Medel, Pérez-Mendoza, & Durán-de-Bazúa, 2010). Nevertheless, due to its seasonal nature, drying process that could prolong the lifespan of rambutan seed without changing the quality, structure and chemical properties is critically needed.

The efficiency drying process is provided through an effective use in term of time, energy and cost. Time effectiveness in the drying process can also be seen through the speed of moisture removal. The moisture removal is directly dependent on the drying method applied. Drying method will affect the technique of moisture movement toward evaporation for the drying process. Moisture movement also depends on the effective moisture diffusivity and activation energy.

Effective moisture diffusivity is defined as moisture movement and closely related to drying rate. These two are the difference as the effective moisture diffusivity is relatively related to moisture velocity within the material, while the drying rate is the moisture vaporizing rate to air or simply a conversion rate of moisture to vapor by evaporation and depend directly on the pressure gradient that exists between material and the air due to a temperature gradient. Meanwhile, effective moisture diffusivity depends directly on the moisture gradient within the material, material structure, and drying method. Thus, the effective moisture diffusivity is among the most important parameters to determine an appropriate drying method to a substance because it helps the moisture movement within the material to facilitate the drying process and thereby achieve equilibrium moisture content or final moisture content that has been set for a substance. Therefore, indirectly, effective moisture diffusivity is the parameter that influences the drying rate of a substance as well as the indicator to determine an appropriate drying method that could extend the product lifespan. Besides, effective moisture diffusivity is also closely related to the activation energy.

Activation energy is moisture particles bonding and needs to be severed for moisture movement. The activation energy is inversely proportional to the effective moisture diffusivity where low activation energy will refer to less energy needed to sever moisture particle bonding and accelerates moisture velocity and provide a higher value of effective moisture diffusivity. This will help to speed up moisture removal process to the environment and to shorten the drying time and promote an appropriate drying process in terms of time and energy consumption. Whereas, if the activation energy is high, the energy requirement to split moisture particle bonding is higher and lessen in moisture velocity and will provide a lower value of effective moisture diffusivity and require a longer drying time.

Evaluation of effective moisture diffusivity and activation energy is often associated with drying characteristics and the main focus previously was based on the effect of drying condition on effective moisture diffusivity and activation energy of product (Aghbashlo, kianmehr, & Samimi-Akhijahani, 2008; Azzouz, Guizani, Jomaa, & Belghith, 2002; Babalis & Belessiotis, 2004; Motevali, Abbaszadeh, Minaei, Khoshtaghaza, & Ghobadian, 2012).It is clearly illustrated via a diversity of foodstuffs that have been studied and have been formulated that 92% of food product fall in effective diffusivity range between 10^{-12} to 10^{-8} m^2s^{-1} (Zogzas, Maroulis, & Marinos-Kouris, 1996). Based on the combination of the author's knowledge, literature based on the interrelationships between the effect of drying method, process variable (Zogzas et al., 1996) and material properties (Xiong, Narsimhan, & Okos, 1991), the effective moisture diffusivity and activation energy have been studied. Conversely, to date, the relationship of effective moisture diffusivity and activation energy on the equilibrium moisture content of rambutan seed as a food waste at two different drying methods; microwave and oven and relation to prolong the lifespan of rambutan seed and promote storage stability is still vague. Hence, there is a need to study the direct relationship between the effective moisture diffusivity and activation energy in predicting an appropriate drying method to achieve an equilibrium moisture content and final moisture content of rambutan seed that led to prolonging lifespan and promote storage stability.

Extending the lifespan of food waste such as rambutan seed is needed as an alternative to save food. This is because, as the ability in the accessibility throughout the year, it will facilitate the conversion of rambutan seed to secondary sources to the industry, thus reducing waste and encourage recycling and reuse of waste to help preserve the environment as well as promoting a sustainable food chain and zero food waste.

The objective of this study is to evaluate the effective moisture diffusivity and activation energy at two drying methods; microwave and oven to determine an appropriate drying method of rambutan seed to achieve an equilibrium moisture content and final moisture content as a tool to extend shelf life and thus provide storage stability. Effect of process variable on effective moisture diffusivity was also reviewed to strengthen the justification for identifying an appropriate drying method to dry rambutan seed. Thus, by knowing the appropriate drying method to prolong the lifespan of rambutan seed, the use of food waste in providing alternative food sources and secondary sources in the industry thus, maximizing the use of natural resources could be realized. Indirectly, it is expected to help address the problems of poverty and hunger in the world, climate changes as well as increasing awareness on how to react to global food loss and waste and ultimately save food.

2. Material and methods

2.1. Material

Rambutan fruits were obtained from University Agricultural Park, Universiti Putra Malaysia (UPM), Selangor. Harvested fruit was stored in zip-lock bag polyethylene at 8.5^{o}C in cool room Faculty of Engineering, Universiti Putra Malaysia prior deseeding. Rambutan seed was manually deseeded, washed, and left at room temperature up to 4 hours to dry up surplus water at seed surface. As surplus water dried, the initial moisture content will be measured using a digital moisture analyzer (OHAUS, MB45, UK) with triplicates. The seed was weighted to (5.0 ± 0.01 g) and heated at 103 ± 0.1^{o}C until a constant weight was achieved.

2.2. Drying

2.2.1. Oven drying

5 g of rambutan seed was dried at two different oven temperatures 40^{o}C and 60^{o}C using an automatic electric oven model OF-22GW (Jelotech, Korea) with duplication. Weight loss was continuously measured every 20 minutes interval using an analytical balance model AY220 (Shimadzu, Japan) until weight between two repeated weighing was less than 0.005 g.

2.2.2. Microwave drying

5 g of rambutan seed was dried at two different level of microwave power 250W and 1000W using commercial microwave oven model NN-C2003S (Panasonic, Malaysia). Weight loss was recorded every 5 minutes interval using an analytical balance model AY220 (Shimadzu, Japan) with precision 0.0001 g until mass do not change between the two weighing interval. Each run was dried in duplicates.

2.3. Effective moisture diffusivity and activation energy

Effective moisture diffusivity value for oven and microwave drying was determined due to the slope of Handerson and Pabis drying model as in Eq. (1) and (2);

$$MR = a\,exp(-kt) \tag{1}$$

$$k = \frac{\pi^2 D_{eff}}{4L^2} \tag{2}$$

where k is a slope from Handerson and Pabis equation, D_{eff} is effective moisture diffusivity (m^2s^{-1}), L is half the thickness of slab (m).

Meanwhile, the activation energy value for the oven and microwave drying was measured based on Eq. (3) and (4) (Dadalı, Apar, & Özbek, 2007; Zogzas & Maroulis, 1996);

$$D_{eff} = D_o exp\left(\frac{-E_a}{RT}\right) \tag{3}$$

where D_o is the pre-exponential factor of the Arrhenius equation (m^2s^{-1}), E_a is the activation energy (kJ mol^{-1}), R is the ideal gas constant (8.3143 kJ $mol^{-1}K^{-1}$) and T is the absolute temperature (K).

$$D_{eff} = D_0 exp\frac{-E_a m}{P_m} \tag{4}$$

where D_o is the pre-exponential factor of the Arrhenius equation (m^2s^{-1}), E_a is the activation energy (Wg^{-1}), m is the weight of the raw material (g) and P is the microwave power (W).

3. Results and discussions

3.1. Effect of drying methods on effective moisture diffusivity

Figure 1 shows the effect of different drying methods on effective moisture diffusivity at two different intensity that represented by number 1 and 2; low and high intensity respectively. Effect of each method was examined at two level of intensity where low levels represent 40°C and 250W and higher levels represented by 60°C and 1000W.

Figure 1 shows that the microwave drying had a higher effective moisture diffusivity value compared to oven drying at low-level microwave power (250W) and oven temperature (40°C), portrayed by the two left vertical bars in figure 1 (labeled as 1). A higher value of effective moisture diffusivity shows faster moisture velocity in the material that will shorten the drying time to achieve the equilibrium moisture content or the targeted final moisture content. Reduction in the drying time indirectly, will reduce energy consumption and in turn, less processing cost. Therefore, microwave drying provides an appropriate drying technique in attaining the equilibrium moisture content (or the targeted final moisture content) and promote storage stability at the low level of oven temperature and microwave power. Less drying time in microwave drying may be due to the drying mechanism involved. A collision between the particles in the seed that leads to the increase in the kinetic energy and in turn generating heat internally accelerating the moisture velocity in the seed. The inherent structure of rambutan seed where the moisture is located in the deepest layers and having low moisture in general, hence, the microwave drying mechanism that heats internally is the most appropriate drying method to accelerate the moisture velocity in the seed towards the seed surface for the drying process to proceed via evaporation. Moisture velocity based on the moisture gradient also fasten moisture velocity and thus shorten the drying time to achieve an equilibrium moisture content or the targeted final moisture content.

However, the dissimilar trend can be observed at higher levels, where oven drying had a higher value of effective moisture diffusivity compared to microwave drying represented by the two right vertical bars in figure 1 (labeled as 2). This may probably due to drying at 1000W happened quickly and 135 minutes of total drying exposure is too long. A higher microwave power leads to huge moisture transfer at the beginning and as the drying proceeded moisture velocity becomes slower due to decrease level in moisture content and total moisture within the seed. Slower moisture velocity would prolong the drying time, lower the drying rate and in turn lessen the value of effective moisture diffusivity. A similar finding has also been observed for the drying of okra, whereas drying proceeded, lower moisture content removed due to a decrease in microwave absorption within the sample. Lower drying rate leading to lower effective moisture diffusivity (Dadalı, Kılıç Apar, & Özbek, 2007). It is suggested if higher microwave powers are required, shorter drying times are recommended.

But, if compared to these two drying methods, microwave drying at lower microwave power, 250 W would be an appropriate drying condition for the rambutan seed to prolong lifespan and longer storage stability. It gives a higher effective diffusivity of moisture, 3.13 x 10^{-7} m^2s^{-1}, shorter drying time thus saving energy and cost.

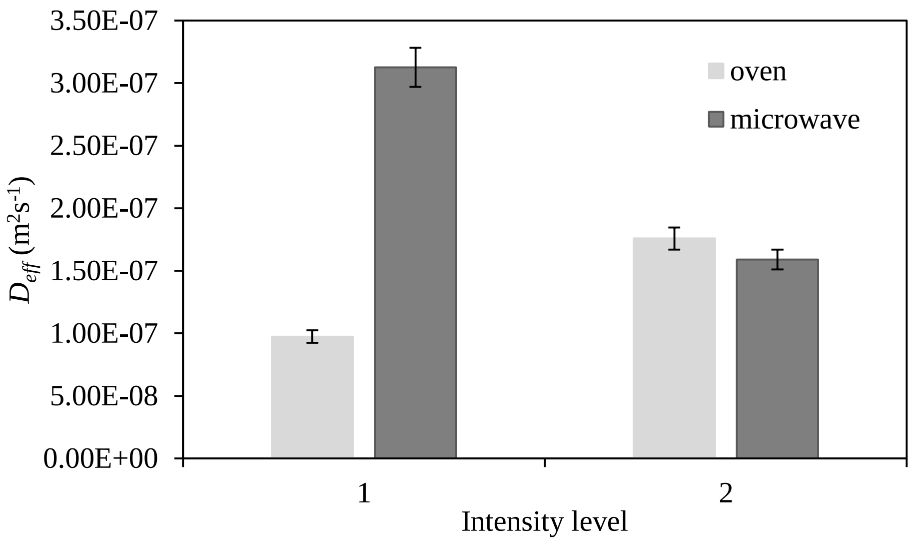

Figure 1: Effect of drying methods on effective moisture diffusivity at two level of intensity 1 and 2; low and high intensity, respectively.

3.2. Estimation of activation energy for each drying method

A higher activation energy represents a higher energy required to break moisture bonding during the drying process. Therefore, a higher activation energy will retard the moisture velocity and may probably give the lower amount of effective moisture diffusivity and thus prolongs the drying process. The value of D_o and E_a in oven drying were respectively estimated as 6.80 x 10^{-4} m^2s^{-1} and 22966.4 kJ mol^{-1} as showed in table 1.

Whereas, the value D_o and E_a were respectively estimated as 1.26 x 10^{-7} m^2s^{-1} and 45.05 Wg^{-1} for the microwave drying as presented in table 1. As activation energy in oven drying is dependent upon the oven temperature and microwave drying is based on the ratio of mass to microwave power applied, then, the activation energy is an unsuitable parameter to be used in comparing these two drying methods in determining an appropriate drying method of rambutan seed. Moreover, as a dissimilar mechanism was applied to split the moisture bonding during microwave and oven drying, thus, activation energy had turn to inappropriate parameter to be used for evaluating drying efficiency within these two drying methods. However, this parameter could be effectively used in comparing within similar drying methods at varied level of process variable for evaluating the effect of process variables on responses to attain an effective drying condition.

Table 1: Estimation of the activation energy for each drying method

	OVEN		MICROWAVE	
D_o	6.80 x 10^{-4}	m^2s^{-1}	1.26 x 10^{-7}	m^2s^{-1}
E_a	22966.4	$kJmol^{-1}$	45.05	Wg^{-1}

3.3. Effect of operational process variable on effective moisture diffusivity

3.3.1. Oven temperature

Figure 2 (a) shows that a higher oven temperature has higher effective moisture diffusivity compared to low oven temperature. A higher effective moisture diffusivity shows rapid moisture velocity and would shorten the drying time to achieve an equilibrium moisture content or the targeted final moisture content. A high temperature leading to a larger value of effective moisture diffusivity most probably due to the higher temperature gradient between seed surface and the air. Moisture removal in the oven drying is based upon the temperature gradient that acting as a driving force for moisture evaporation in the drying process. Therefore, high temperature would provide a greater driving force due to the larger temperature gradient that will expedite the moisture velocity from inner seed to the seed surface for evaporation to occur. Faster moisture velocity will decrease the drying time. As the drying time decreases, energy consumption will be reduced and in turn, would provide lower drying cost and promote an effective drying method for storage stability. Thus, 60°C in oven drying would be an appropriate drying condition to dry rambutan seed for storage stability compared the lower drying temperature of 40°C. The value for the effective moisture diffusivity for 40°C and 60°C are 9.74 x 10^{-8} m^2 s^{-1} and 1.76 x 10^{-7} m^2s^{-1} respectively.

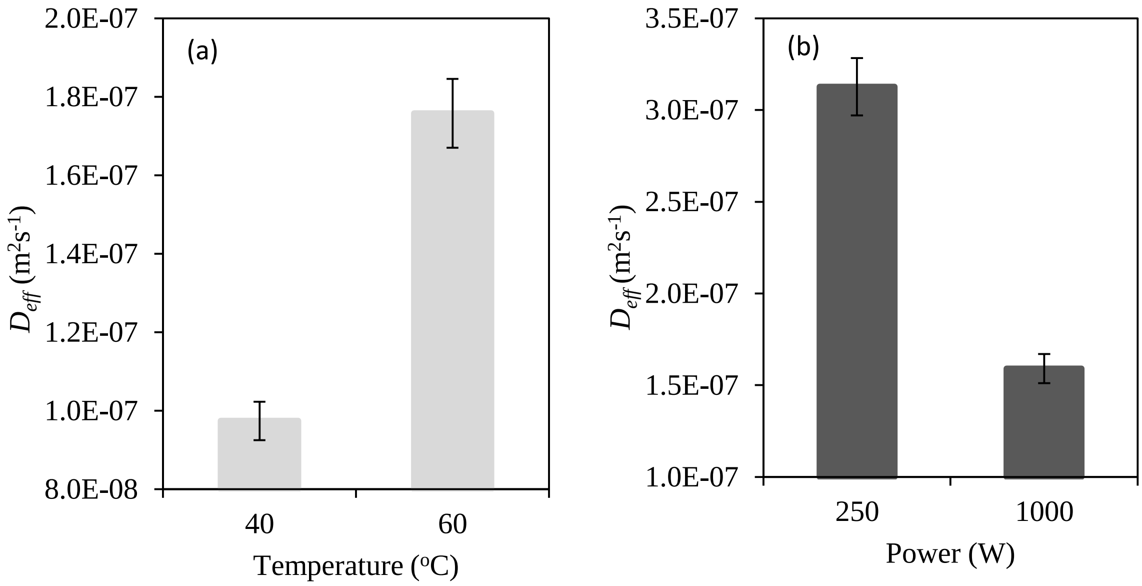

Figure 2: Effect of operational process variable on effective moisture diffusivity (a) Effect of oven temperature; (b) Effect of microwave power

3.3.2. Microwave power

Figure 2 (b) shows a low microwave power exhibit a higher effective moisture diffusivity for the rambutan seed compared to a high microwave power. This may probably due to drying mechanism in the microwave is based on the moisture gradient and the heat generated internally to accelerate the drying process. Therefore, a lower microwave power is required for moderate drying exposure or a short drying exposure if dried at higher microwave power, 1000W as applied in this study. A longer drying exposure at a high microwave power will reduce the drying rate and slow the moisture velocity within the material providing a lower value of effective moisture diffusivity. This may probably occur due to drying using a high microwave power will accelerate the moisture velocity and shorten the drying time. However, when the drying time is extended to achieve an equilibrium moisture content, the moisture content will be too low and the process for moisture removal as well as moisture velocity are too slow due to at this stage, the moisture often locates in the innermost layer of the seed. As moisture velocity is slow, a longer drying time and more energy are required that would lead to increase the drying cost. Therefore, with respect to microwave power, a lower microwave power, 250W become an appropriate drying condition for rambutan seed to prolong the lifespan. The value of effective moisture diffusivity for both microwave power of 250 and 1000 W is 3.13 x 10^{-7} m^2s^{-1} and 1.59 x10^{-7} m^2s^{-1}, respectively.

4. Conclusions

Based on this study, a high amount of effective moisture diffusivity was obtained at a high oven temperature (60^{o}C) and a low microwave power (250W); 1.76 x 10^{-7} m^2s^{-1} and 3.13 x 10^{-7} m^2s^{-1}, respectively. A higher value of effective moisture diffusivity would accelerate moisture velocity within rambutan seed to facilitate moisture removal to achieve equilibrium moisture content at specified relative humidity. Therefore, a higher value of effective moisture diffusivity would be an appropriate parameter to design an effective drying method in terms of time as well as savings in the energy consumption and cost to prolong the lifespan of rambutan seed and promoting its storage stability. With respect to both drying methods applied and the range studied, a low microwave power (250W) become an appropriate drying method for rambutan seed to prolong its lifespan and storage stability.

Acknowledgements

The authors gratefully acknowledge Universiti Putra Malaysia (UPM) for IPS research grant (vote no. 9464600) and Ministry of Higher Education as well as Applied Science Faculty, UiTM, Shah Alam for financial sponsored throughout this study.

References

Aghbashlo, M., kianmehr, M. H., & Samimi-Akhijahani, H. (2008). Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thin-layer drying of berberis fruit (Berberidaceae). *Energy Conversion and Management*, *49*(10), 2865–2871. https://doi.org/10.1016/j.enconman.2008.03.009

Azzouz, S., Guizani, A., Jomaa, W., & Belghith, A. (2002). Moisture diffusivity and drying kinetic equation of convective drying of grapes. *Journal of Food Engineering*, *55*(4), 323–330. https://doi.org/10.1016/S0260-8774(02)00109-7

Babalis, S. J., & Belessiotis, V. G. (2004). Influence of the drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs. *Journal of Food Engineering*, *65*(3), 449–458. https://doi.org/10.1016/j.jfoodeng.2004.02.005

Dadalı, G., Apar, D. K., & Özbek, B. (2007). Estimation of Effective Moisture Diffusivity of Okra for Microwave Drying. *Drying Technology*, *25*(9), 1445–1450. https://doi.org/10.1080/07373930701536767

Dadalı, G., Kılıç Apar, D., & Özbek, B. (2007). Microwave drying kinetics of okra. *Drying Technology*, *25*(5), 917–924. https://doi.org/10.1080/07373930701372296

FAO. (2015). Global initiative on food loss and food waste reduction. *United Nations*, 1–8. Retrieved from http://www.fao.org/save-food/en/

Geankoplis, J. C. (2003). Drying of Process Materials. In *Transport Processes and Unit Operations*

(Fourth, pp. 559–624). New Jersey: Prentice Hall.

Hussin, M. (2015, October). Snek biji rambutan. *Agro, Harian Metro*, p. 2. Malaysia.

Issara, U., Zzaman, W., & Yang, T. A. (2014). Rambutan seed fat as a potential source of cocoa butter substitute in the confectionary product. *International Food Research Journal*, *21*(1), 25–31.

Lourith, N., Kanlayavattanakul, M., Mongkonpaibool, K., Butsaratrakool, T., & Chinmuang, T. (2016). Rambutan seed as a new promising unconventional source of specialty fat for cosmetics. *Industrial Crops and Products*, *83*, 149–154. https://doi.org/10.1016/j.indcrop.2015.12.045

Motevali, A., Abbaszadeh, A., Minaei, S., Khoshtaghaza, M. H., & Ghobadian, B. (2012). Effective Moisture diffusivity, activation energy and energy consumption in the thin-layer drying of jujube (Zizyphus jujube Mill). *Journal of Agricultural Science and Technology*, *14*(3), 523–532.

Soeng, S., Evacuasiany, E., Widowati, W., & Fauziah, N. (2015). Antioxidant and hypoglycemic activities of extract and fractions of Rambutan seeds (Nephelium lappaceum L.). *Biomedical Engineering*, *1*(1), 13–18.

Soeng, S., Evacuasiany, E., Widowati, W., Fauziah, N., Manik, V., & Maesaroh, M. (2015). Inhibitory potential of rambutan seeds extracts and fractions on adipogenesis in 3T3-L1 cell line. *Journal of Experimental and Integrative Medicine*, *5*(1), 55–60. https://doi.org/10.5455/jeim.200115.or.120

Solís-Fuentes, J. a., Camey-Ortíz, G., Hernández-Medel, M. D. R., Pérez-Mendoza, F., & Durán-de-Bazúa, C. (2010). Composition, phase behavior and thermal stability of natural edible fat from rambutan (Nephelium lappaceum L.) seed. *Bioresource Technology*, *101*(2), 799–803. https://doi.org/10.1016/j.biortech.2009.08.031

Xiong, X., Narsimhan, G., & Okos, M. R. (1991). Effect of composition and pore structure on binding energy and effective diffusivity of moisture in porous foods. *Journal of Food Engineering*, *15*, 187–208.

Zogzas, N. ., Maroulis, Z. B., & Marinos-Kouris, D. (1996). Moisture diffusivity data compilation in foodstuffs. *Drying Technology*, *14*(10), 2225–2253. https://doi.org/10.1080/07373930701438592

Zogzas, N. P., & Maroulis, Z. B. (1996). Effective moisture diffusivity estimation from drying data. A comparison between various methods of analysis. *Drying Technology*, *14*(7 & 8), 1543–1573. https://doi.org/10.1080/07373939608917163