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ORIGINAL ARTICLE

Drying Characteristics of *Garcinia atroviridis*

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ABSTRACT

Some physical and chemical properties of fresh garcinia fruits are reported. The most suitable drying conditions for garcinia material in a tray dryer based on the final moisture content were determined by extensive testing. It was found that for the material thickness of 2, 4 and 6 mm, a temperature of 55 °C and air velocity of 1.2 m/s are suitable for drying. The most suitable time where the final moisture content met the commercial standard was found to be 199, 256 and 427 min, respectively. The higher the temperature, the shorter the drying time. It was also observed that the suitable drying time for 2-mm thick material and air velocity of 1.2 m/s was 199, 159 and 99 min for drying temperature of 55, 65 and 75 °C, respectively. Drying characteristics are also reported. Most of the drying rate curves appear in a falling rate period except at low temperature and low velocity of operation parameters i.e. 55 °C and 0.5 m/s for 4-mm thick material, where the constant drying rate is approximately 0.09 kg water/min.m^2. The sorption isotherm is sigmoidal shape at 30 °C and monolayer moisture content is 14.78 kg water/100 kg dry solid. Soaking material in 1.5 and 3.0 %w/w sodium chloride did not affect the drying rate. Effective moisture diffusivities were evaluated to be 5.57×10^{-10}, 6.94×10^{-10} and 1.11×10^{-9} m^2/s at temperatures 55, 65 and 75 °C, respectively.

Keywords: Garcinia fruit, *Garcinia cambogia*, *Garcinia atroviridis,* drying, characteristics, drying time, tray dryer, sorption isotherm

INTRODUCTION

Garcinia is a medium to large evergreen tree, whose scientific name is *Garcinia cambogia* for the strain found in Southeast India and *G. atroviridis* for the one in Southern Thailand and Northern Malaysia. Garcinia fruit has been used as food for centuries in many areas of tropical Asia. The fruit may resemble a small yellow or reddish pumpkin, or it may have a unique purple color [1]. Both *G. cambogia* and *G. atroviridis* have been traditionally used in food preparation and cooking, having a distinctive sweet acid taste and are reported to make meals more filling [2]. However fully ripe, it is too acidic to eat fresh [1].

(-)-Hydroxycitric acid (HCA) is claimed to be an effective ingredient extracted from the rind or pericarp of garcinia fruit. It inhibits adenosine triphosphate citrate lyase, the enzyme that is specifically responsible for the conversion of carbohydrates to fat [3]. Hence it has been used in the treatment of obesity [4,5]. HCA, the major organic acid in the fruit, is found to have a concentration of 16 - 18 %w/w [6].

In Southern Thailand, garcinia plants can be found in numerous areas such as Yala, Pattani, Narathivat, Phangnga, Ranong, Chumphon and Nakhon Si Thammarat. The growing plants are found in regions no higher than 600-meters above sea level [7]. The juice product from garcinia fruit is favored by a lot of consumers. However, the production in Thailand is somewhat traditional and in the context of household industries [8].

The fruit offspring is found to be twice a year that is April to May and October to November. Due to these short periods and the number of fruit produced each year, the traditional method of preservation is slicing of the garcinia into thin slabs and further dehydrated by sun drying in air and subsequent heat convection. The dried materials will later be kept for a certain period before entering the leaching process of juice production.

The problem associated with the traditional method is that the quality of the dried materials is difficult to control. The reason is because the drying took place by nature. Generally, in food drying, the material must be dried to obtain a final moisture content of around 4 - 6 % wet basis [9]. A suitable final moisture content helps to lengthen the storage life of foodstuffs.

A cabinet tray dryer is a conventional tool that is suitable for solid materials such as grains, sliced fruits and vegetables or chunked products. The fruit industry uses this type of dryer in a variety of processes of which several commercial alternatives are available [10]. The reason is due to its simplicity and versatility [11]. In addition, to the best of our knowledge, there is still no report on the drying characteristics of this kind of fruit. This paper thus aims to investigate the influence of different drying conditions by a cabinet tray dryer on characteristic curves of garcinia. Hence, the appropriate conditions for water removal from the fruit can be determined. In addition, other drying parameters concerned such as sorption isotherm and effective diffusivity are also reported.

MATERIALS AND METHODS

Sample Preparation

Fresh garcinia fruits, green in color, were purchased locally. The average weight of each was selected to be 300 - 350 g. The unpeeled fruits were cut into flat slabs to the required thickness, that was 2, 4 or 6 mm, depending on each required experiment. The diameter of slab was in the range of 7 - 10 cm. The skin was not removed to prevent moisture diffusion and evaporation in the radial dimension.

Quality of Raw Material: Some Physical and Chemical Properties of Garcinia Fruit

To obtain density and initial moisture content of garcinia, 30 fruit samples were used. The skin was removed manually with a knife and the fruits were cut into small pieces with dimensions of 2 - 4 mm. The density of garcinia was measured by a 25-ml picnometer and moisture content was determined by vacuum oven. The color in the Hunter system of fresh fruit slice was examined by colorflex instrument model JP 7100 F. In addition, the firmness of unpeeled fruits was measured by a texture analyzer (Stable Microsystem, model TA-TX 2i) using a solid cylinder probe with a diameter of 2 mm punched into the whole fruit at 10 different points around its circumference with a penetration distance of 5 mm and velocity of 1.5 mm/s, with a compression force of 5 kg. Total acidity as citric acid was carried out by the AOAC method while the total soluble solid was determined by a hand-held refractometer.

The Influence of Drying Temperature, Air Velocity and Thickness of Prepared Materials on The Drying Characteristics of Dried Samples

The effect of drying temperature, air velocity and thickness of prepared fruits were investigated. Unpeeled garcinia fruits were sliced and divided into three groups with different thickness, i.e. 2, 4 and 6 mm. Drying temperatures in the tray dryer were varied 55, 65 and 75 °C. Air velocity flowing parallel to the material surface was selected to be 0.5, 0.8 and 1.2 m/s. Thus the total numbers of drying experiments were 27. Each experiment was repeated twice.

Thirty pieces of garcinia samples from each experiment were randomly selected their weights and exposed drying area measured by a 3 digit-balance (Mettler Toledo, Model PG 5002) and a planimeter (Placom Brand, Model KP –92N), respectively. Initial moisture content was then determined using a vacuum oven at 70 °C for 24 h. Samples from each experiment were placed on a single layer of a single steel tray (50 cm wide × 70 cm long) in the drying chamber. The sample weight was measured every 20 min when the sample thickness was 2 mm and every 30 min when the thickness was 4 and 6 mm. This was continued until each weight was nearly constant, then they were left for at least 24 h to obtain equilibrium. The relative humidity of the drying chamber was found to be 20±5 % RH by recording the wet and dry bulb temperatures.

Sample weight versus time was converted to free moisture content ($X-X_e$) versus time (t) to obtain a drying curve, where X and X_e are moisture contents in dry basis at any time and at equilibrium, respectively. The drying rate curve (R) versus free moisture content ($X-X_e$) was then plotted, using the relationship:

$$R = -\frac{L_S}{A}\frac{d(X - X_e)}{dt} \tag{1}$$

where L_S is the weight of dry solid used (kg); A is the exposed area for drying (m^2); X and X_e are the moisture contents (dry basis) at time t and at equilibrium (kg water/kg dry solid); and t is the drying time (min). In addition, it was assumed that no shrinkage took place [9].

Effect of Soaking The Raw Material in Sodium Chloride Solution

Garcinia samples with thickness of 2 mm were separated into 2 parts, one was soaked in 1.5 %w/w NaCl and the other one was soaked in 3.0 %w/w NaCl. Both were left for 24 h and then drained for 15 min. The samples were thus measured for their initial moisture content and the exposed surface area. Then both were dried according to selected conditions. Drying characteristics were interpreted in the same way as non soaked material. A 2-mm thick sample without soaking was used as a control treatment.

The selected drying condition was that the temperature of 75 °C and the air velocity of 1.2 m/s. The selection was based on the shortest time where moisture content of the dried products met the commercial standard.

Sorption Isotherm Measurement

The peeled garcinia fruit was sliced and cut into thickness of 2 mm with a diameter of 7 cm and then put in a shelf-life's test cabinet (CONTERM Brand, Model CAT 610/620). All tests were run in static conditions and on automatic control by water spraying inside the test chamber at required set-up temperature to obtain selected relative humidity. Cabinet temperatures were set to be 30, 40, and 50 °C and the relative humidity was controlled to be 10, 30, 50, 70, and 90 %, respectively. Each treatment was done 3 times. After the system reached its equilibrium condition (several days or 24 h at least), the sample was brought to measure its equilibrium moisture content and then water activity (A_w) was calculated,

$$A_W = \%\ \text{equilibrium relative humidity in the surrounding atmosphere}/100 \quad (2)$$

Effective Moisture Diffusivity Evaluation

Moisture diffusivity is a parameter that depends on temperature, thus the temperature was varied. The 2-mm thick sample was subjected to the highest air velocity of 1.2 m/s, where the surface heat resistance could be negligible and was selected for evaluation.

The effective moisture diffusivity was calculated using the following analytical solution based on Fick's second law for unsteady state diffusion. The relation given in relates the total amount of moisture leaving an infinite slab with a surface flux to the drying time [12].

$$\frac{X-X_e}{X_o-X_e}=\frac{8}{\pi^2}\left[\sum_{n=0}^{n=\infty}\frac{1}{(2n+1)^2}\exp\left[-(2n+1)^2 D_{eff}\, t\,(\pi/2L)^2\right]\right] \quad (3)$$

where X, X_e and X_o are the average moisture content (dry basis) at any time t in falling rate period, equilibrium, and initial moisture contents, respectively, (kg water/kg dry solid); D_{eff} is the effective diffusion coefficient (m^2/s); L is the half-thickness of a solid layer through which diffusion occurs (m). Nevertheless, L is the total thickness, when evaporation is only from one side. All experiments in this paper fall into the later category. The reason is because the tray used is insulated.

Eq. (3) assumes that D_{eff} is constant and that shrinkage of the sample is negligible. For long drying times, the terms in the above infinite series are expected to converge rapidly and may be approximated by the first term [13,14]. Equation (3) is thus simplified to

$$MR=\frac{X-X_e}{X_o-X_e}=\frac{8}{\pi^2}\exp\left(\frac{-D_{eff}\pi^2 t}{4L^2}\right) \quad (4)$$

here MR is known as the characteristic moisture ratio. The effective moisture diffusivity, D_{eff} was determined from the slope $\left(-D_{eff}\pi^2/4L^2\right)$ of the plot of ln (MR) against time t.

RESULTS AND DISCUSSION

Some Physical and Chemical Properties of Garcinia Fruit

The garcinias studied were less than 3 months old since fruit setting. This period is favorable because of their freshness and simplicity in handling and processing [8]. According to **Table 1**, it was found that the average moisture content is 86.47 %, total soluble solid is 6.34 % and total acidity as citric acid is very high at 5.54 %w/w wet basis. Thus total acidity is calculated to be 40.95 % dry basis. This is the reason why it has a highly distinctive acid taste in comparison to other fruits from the same family such as *G. mangostana* and *G. schomburgkiana* where acidity is found to be 20 - 30 % dry basis [8].

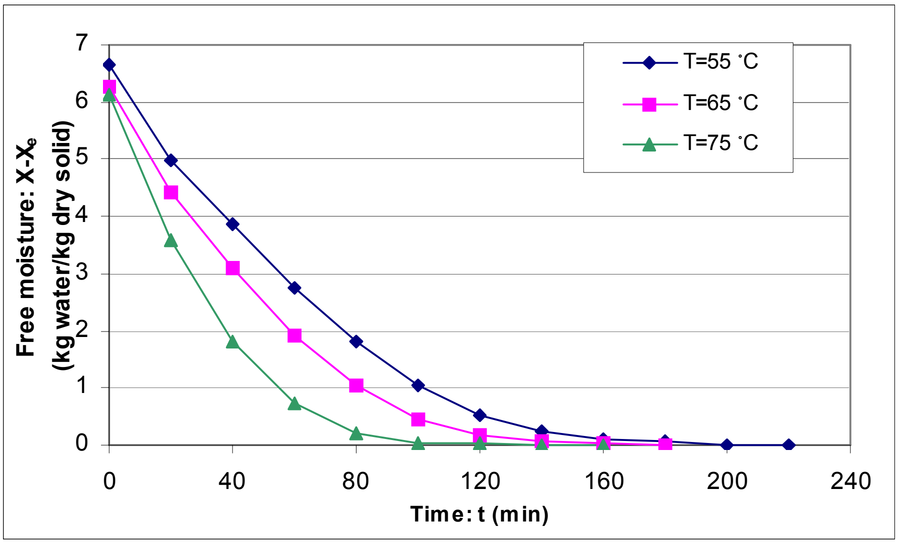
Physical properties like firmness and color could be used as a fruit maturity index since these properties change with time. Moreover, the appropriate properties for harvesting and processing can be determined by its specific gravity (thus density will be known). Garcinia fruit density where the fruit was in an appropriate handling period, not too hard or soft in texture, was found to be 1,035 kg/cm^3. Firmness was observed to be very high at 85.14 N. We suggest that this is due to highly non-soluble pectic compounds, which is mostly responsible for general fruit texture [15]. The color in the Hunter system was as follows: L value (lightness) was 66.30, a value (light green attribute) is –1.42 and b value (yellow attribute) was 27.57.

Table 1 Some physical and chemical properties of Garcinia Fruit (*Garcinia atroviridis*).

Composition	$\overline{X} \pm SD$
Moisture content (% wet basis)	86.47±1.35
Total acidity as citric acid (%w/w)	5.54±0.13
Total soluble solid (%)	6.34±0.25
Firmness (N)	85.14±1.89
Density (kg/m^3)	1,035.00±0.03
Color value:	
L (lightness)	66.30±0.33
a (light green attribute)	–1.42±0.69
b (yellow attribute)	27.57±1.08

The Influence of Drying Temperature, Air Velocity and Thickness of Prepared Materials on Drying Characteristics

Some experiments were selected and shown for the results and discussion. It was found that the drying temperature and air velocity had significant influences on both the drying time and drying rate curve. The higher the temperature, the shorter the drying time (**Figure 1a**) and faster the drying rate (**Figure 1b**). The higher air velocity leads to the same conclusion as that for the temperature (**Figure 2**). From the temperature investigation, similar results as those in **Figure 1** are also found for other



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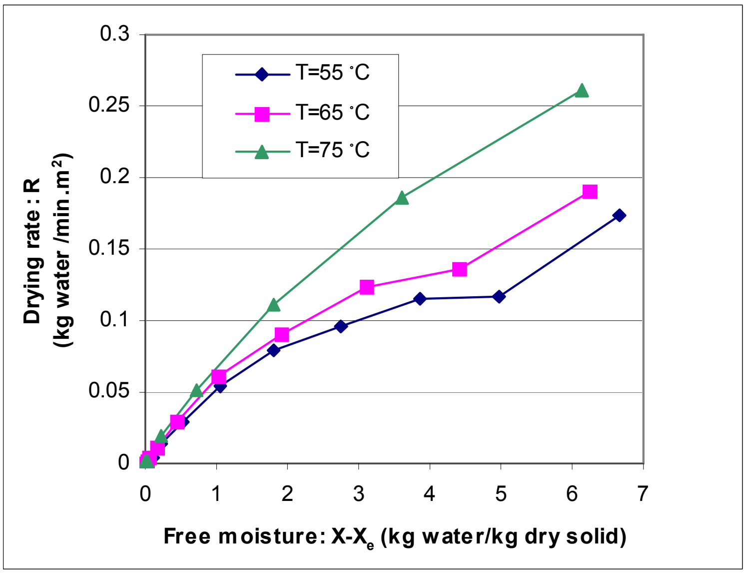
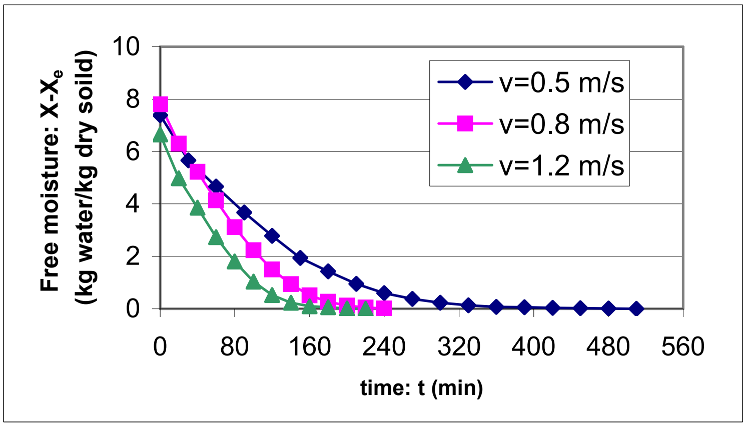


(b)

Figure 1 Influence of temperature on drying of garcinia materials with a thickness of 2 mm subjected to air at a velocity of 1.2 m/s: (a) drying curve, (b) drying rate curve.

material thicknesses (4 and 6 mm) and other air velocities (0.5 and 0.8 m/s) (data not shown). In addition, for the velocity study, the same pattern as that shown in **Figure 2** is also found for other material thicknesses (4 and 6 mm) and other temperatures (65 and 75 °C) (data not shown).



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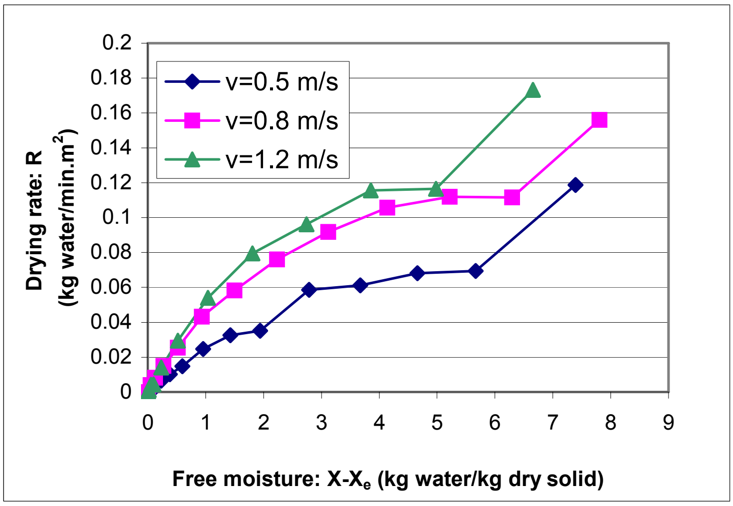


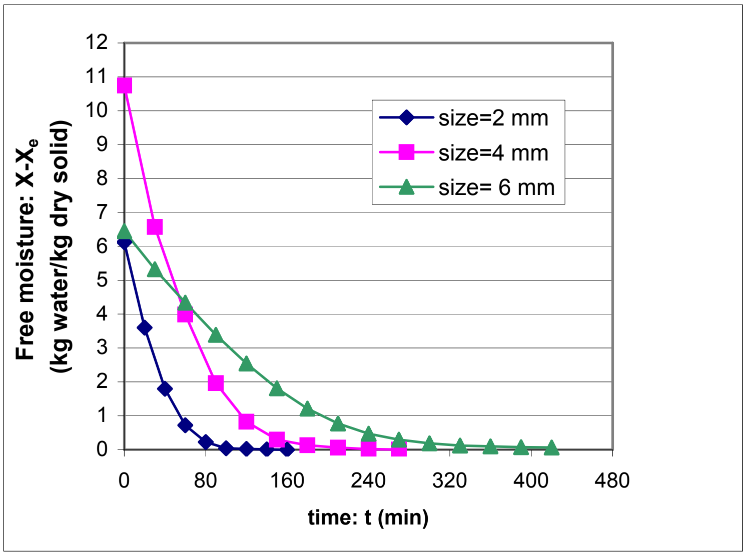
(b)

Figure 2 Influence of air velocity on drying of garcinia materials with a thickness of 2 mm subjected to temperature of 55 °C: (a) drying curve, (b) drying rate curve.

Consequently, a temperature of 75 °C was selected for the reason that it is the highest tolerance value for most fruit species, where general appearances are still acceptable [16]. In addition, it was revealed that air velocities higher than 1 - 2 m/s had no effect on drying rate [16,17].

The thickness of raw material leads to no certain conclusion on drying rate trends (**Figures 3a** and **b**). Similar results are also found in most other treatments that used different temperature and air velocity (data not shown). As claimed by Tamon, cited by Thanthapanichkul, [18]; these drying rate curves are typical in each case of a capillary mechanism. In addition, according to Geankoplis, [9], if the drying mechanism at falling rate period is only by diffusion, drying rate depends on material thickness. Hence, for garcinia fruit, the results lead to the conclusion that the drying mechanism may not only be by diffusion and capillary reaction may play a major role.

According to **Figure 1b**, **Figure 2b** and **Figure 3b**, only falling rate periods are observed. Drying characteristic curves are clearly seen when the material thickness is 2 mm and the temperature is 55 °C and the air velocity 0.5 m/s (**Figure 4**). In addition, a constant rate period seems observable for material thicknesses of 4 and 6 mm. The characteristics shown in **Figure 4** are similar to that obtained for drying carrots at 80 °C, air velocity of 3 m/s, and controlled RH of 11 % and 25 %, respectively [18].



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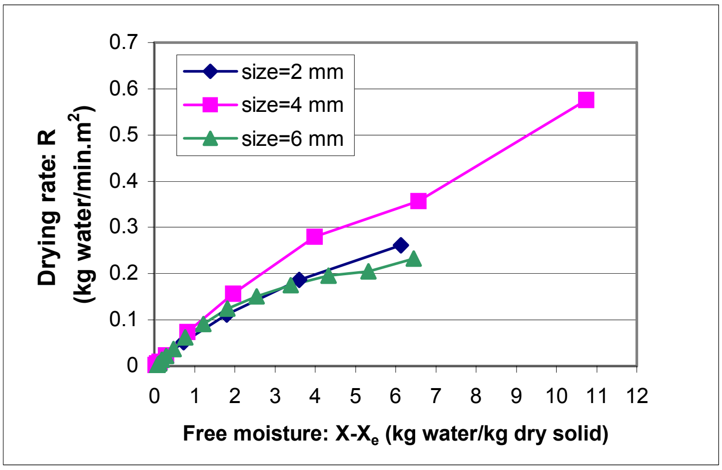
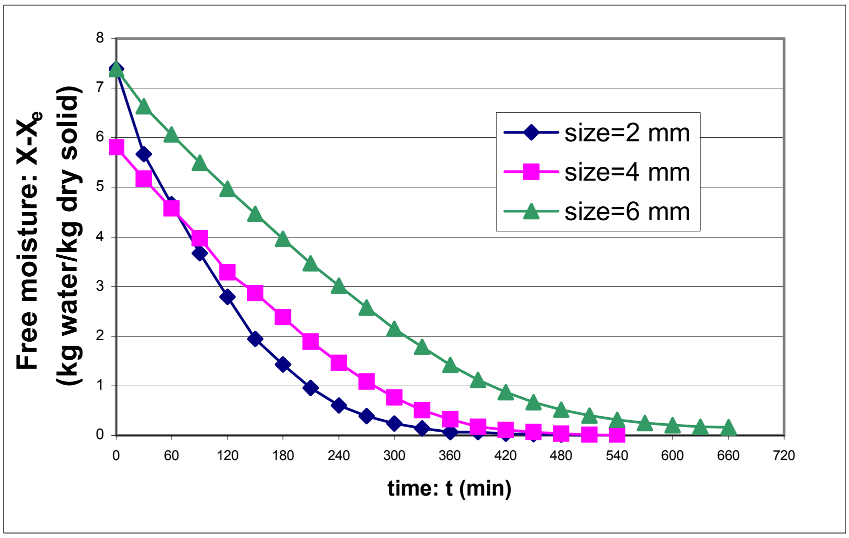


(b)

Figure 3 Influence of thickness of garcinia materials subjected to an air velocity of 1.2 m/s and a temperature of 75 °C: (a) drying curve, (b) drying rate curve.

The combined influence of temperature and air velocity on the drying characteristics can also be seen in **Figure 5**. At higher temperature and air velocity there to no constant rate period and the drying rate thus reduces sharply (75 °C temperature and 0.5 m/s velocity, for example), where as a constant rate period (R = 0.09 kg water/min.m^2) can clearly be seen under low drying conditions (55 °C temperature and 0.5 m/s velocity).



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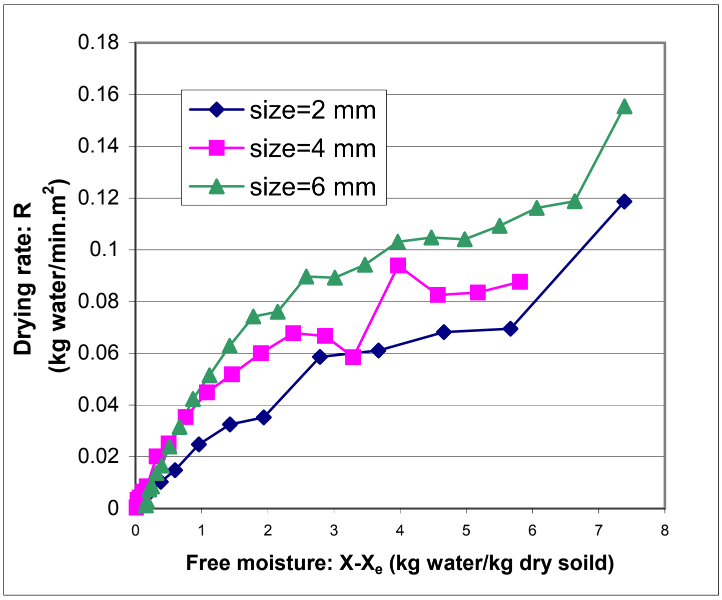
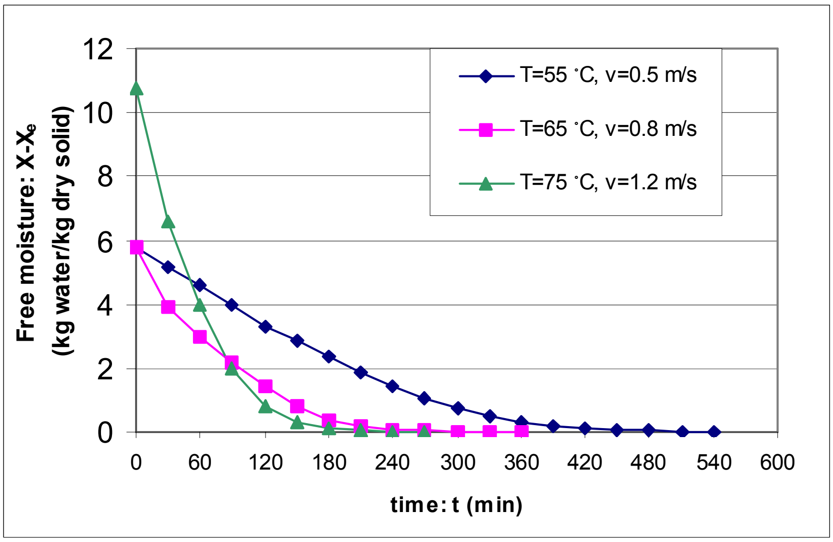


(b)

Figure 4 Drying characteristics curve of garcinia materials with different thickness that subjected to air velocity of 0.5 m/s and temperature of 55 °C: (a) drying curve, (b) drying rate curve.



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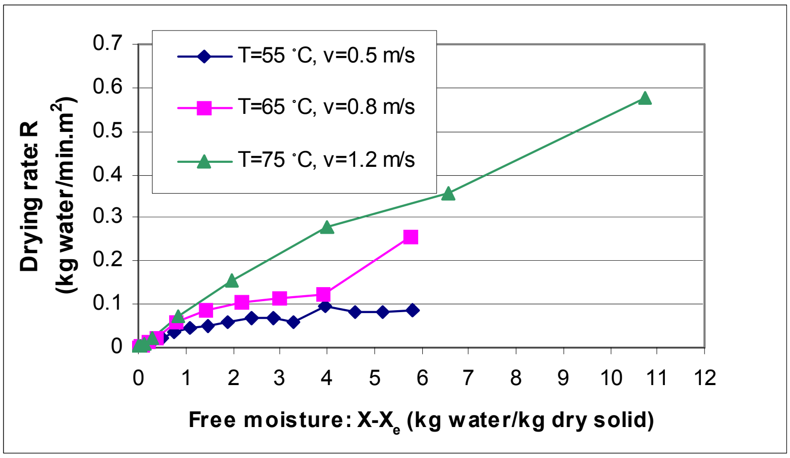


(b)

Figure 5 Influence of combined between air velocity and temperature on the drying characteristics of garcinia materials with 4-mm thickness: (a) drying curve, (b) drying rate curve.

According to this research, all samples were run until equilibrium was achieved. Final moisture contents were found to be 4 - 6 % dry basis or 3.8 - 5.7 % wet basis, thus meeting the requirement of the upper allowable limit for commercial standard of vegetables, which is less than 7 % wet basis (7.5 % dry basis) [19]. The purpose is to prevent fungal growths, transpiration and microbial deterioration.

Based on the required commercial standard for moisture content, suitable drying times for each material thickness and drying temperature when the air velocity was fixed at 1.2 m/s were calculated and detailed in **Table 2**.

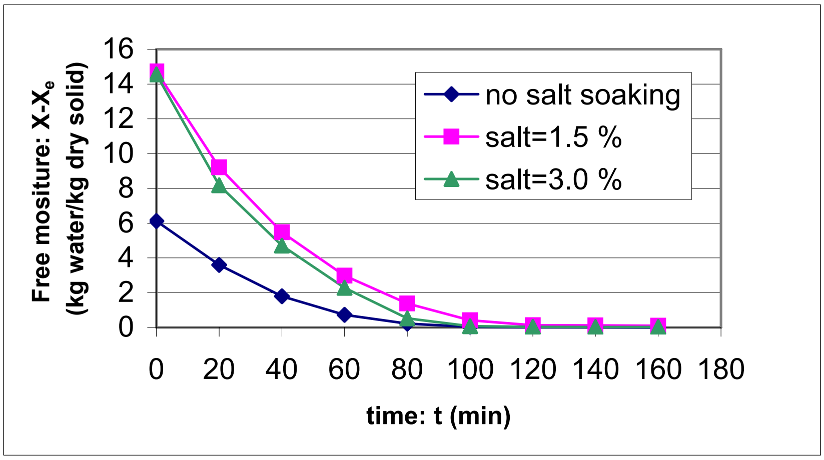
Table 2 Suitable drying times (min) for garcinia material where the final moisture content met the required commercial standard when the air velocity was fixed at 1.2 m/s, RH = 20±5 %.

Material thickness (mm)	**Drying times** (min) **at different temperatures** (°C)		
	55	**65**	**75**
2	199	159	99
4	256	219	N/A*
6	427	459	N/A*

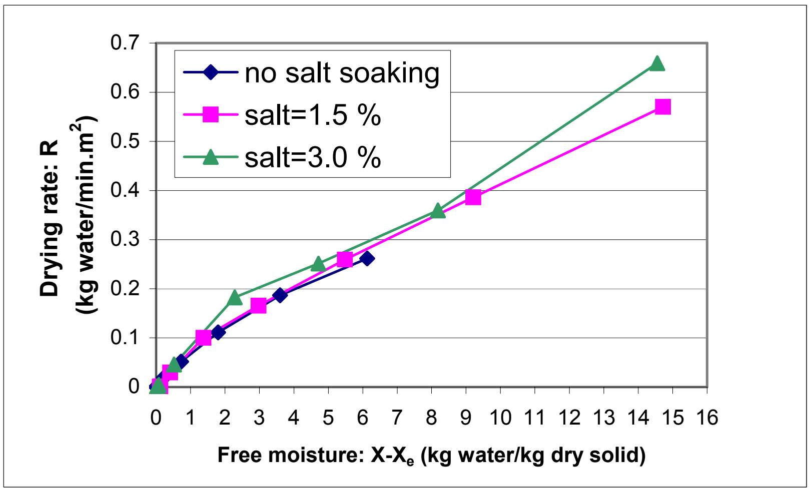
* Not available

Effect of Material Soaking in Sodium Chloride Solution

Material soaking in a sodium chloride solution results in an effect on the initial moisture content of the garcinia sample in comparison to no soaking treatment. However, it does not obviously improve the drying rate (**Figure 6**). This may be because the concentration of the solution is too low. Nevertheless, it is claimed that sodium chloride helps to lengthen the storage time of dried materials [20].



(a)

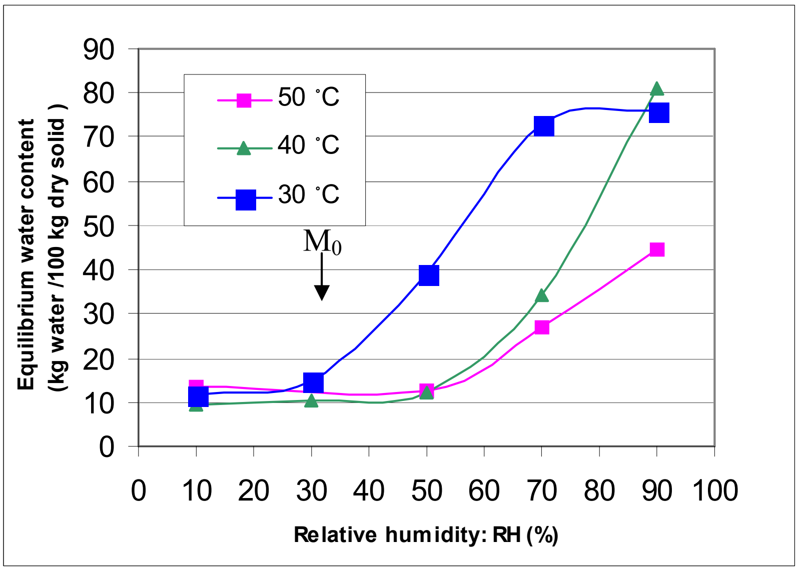


(b)

Figure 6 Influence of pretreatment of sodium chloride solution soaking on the drying characteristics of garcinia materials with 2-mm thickness subjected to a drying temperature of 75 °C and an air velocity of 1.2 m/s: (a) drying curve, (b) drying rate curve.

Sorption Isotherm

The sorption isotherm is obviously sigmoidal shape at a constant temperature of 30 °C (**Figure 7**), the general pattern of food materials [21]. The monomolecular moisture content (M_0) is approximately high to 14.78 kg water/100 kg dry solid (12.9 % wet basis). At higher temperatures (i.e. 40 and 50 °C), the S-shape fades off.



(a)

Figure 7 Sorption isotherm of garcinia fruit at different temperatures.

The S-shape is frequently found for cereals and their products at 25 °C, where the two broken points are presented at A_w 0.2 - 0.4 {20 - 40 % ERH (equilibrium relative humidity)} and 0.6 - 0.7 (60 - 70 % ERH). This phenomena is due to the mechanism of water addition, capillary reaction and surface-water interaction [21]. This result is quite similar to that obtained for garcinia fruit at 30 °C (**Figure 7**), where the broken point is around 30 and 70 % ERH (14.78 and 70.36 kg water/100 kg dry solid, respectively). Moreover, garcinia humidity of which the A_w value is less than 0.6 (60 % ERH), the inhibition index of microbial growth, is calculated to be 56.2, 23.2 and 19.7 kg water/100 kg dry solid for the temperatures of 30, 40 and 50 °C, respectively.

Effective Moisture Diffusivity

Effective moisture diffusivity is calculated to be 5.57×10^{-10}, 6.94×10^{-10} and 1.11×10^{-9} m^2/s for the temperature of 55, 65 and 75 °C, respectively. The higher the temperature, the higher the diffusivity obtained. The results accordingly fall into the normal range of diffusivity for food materials [22], which is generally found to be 10^{-9} - 10^{-11} m^2/s.

Reynold numbers (Re) for force convection of air velocity flowing parallel to flat plate are calculated to be greater than 53,804 for all treatments.

CONCLUSIONS

Some physical and chemical properties of fresh garcinia fruits are established. Suitable drying conditions for garcinia materials in a tray dryer based on the final moisture content have been determined. Drying characteristics such as drying curve, drying rate curve and sorption isotherm are reported. Soaking the material in a 1.5 or 3.0 %w/w sodium chloride solution resulted in no effect on the drying characteristics. Suitable drying times for each material thickness at different temperatures, where the air velocity was fixed at 1.2 m/s, are reported. Effective moisture diffusivity was evaluated at different temperatures and the values obtained fall in the normal range for food materials.

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บทคัดย่อ

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คุณลักษณะเฉพาะของการอบแห้งส้มแขก *Garcinia atroviridis*

งานวิจัยนี้เป็นการศึกษาคุณสมบัติทางเคมีและทางกายภาพบางประการของผลส้มแขกสด และกำหนดสภาวะเหมาะสมในการอบแห้งส้มแขกในเครื่องอบแห้งแบบถาด โดยใช้ความชื้นสุดท้ายที่เหมาะสมในเชิงพาณิชย์เป็นเกณฑ์ จากการทดลองพบว่า อุณหภูมิของการอบแห้งที่ 55 องศาเซลเซียสและความเร็วลม 1.2 เมตรต่อวินาที สำหรับชิ้นส้มแขกที่มีความหนา 2, 4 และ 6 มิลลิเมตร เวลาที่ใช้ในการอบแห้งจะมีค่าเป็น 199, 256 และ 427 นาที ตามลำดับ เมื่อใช้อุณหภูมิในการอบแห้งสูงขึ้น เวลาที่ใช้ในการอบแห้งจะลดลง จากการศึกษาพบว่า ชิ้นส้มแขกที่มีความหนา 2 มิลลิเมตร ได้รับความเร็วลม 1.2 เมตรต่อวินาที จะใช้เวลาใน การอบแห้งเป็น 199, 159 และ 99 นาที เมื่ออุณหภูมิอบแห้งเป็น 55, 65 และ 75 องศาเซลเซียส ตามลำดับ เมื่อแสดงคุณลักษณะเฉพาะของการอบแห้งส้มแขก ในรูปกราฟแสดงการอบแห้ง อัตราการอบแห้งและไอโซเทอร์มของการดูดซับ พบว่า กราฟอัตราการอบแห้งส่วนใหญ่อยู่ในช่วงอัตราการอบแห้งลดลง ยกเว้นที่ค่าพารามิเตอร์ของการทดลองต่ำๆ เช่น ที่ความหนา 4 มิลลิเมตร อุณหภูมิ 55 องศาเซลเซียสและความเร็วลม 0.5 เมตรต่อวินาทีจะพบช่วงอัตราการอบแห้งคงที่โดยมีค่าอัตราการระเหยเป็น 0.09 กิโลกรัมน้ำต่อนาทีต่อตารางเมตร เส้นโค้งไอโซเทอร์มของการดูดซับเป็นรูปตัวเอส ที่อุณหภูมิ 30 องศาเซลเซียสและค่าความชื้นที่ชั้นโมโนมีค่าเป็น 14.78 กิโลกรัมน้ำต่อ 100 กิโลกรัมของแข็งแห้ง การแช่ชิ้นวัสดุส้มแขกในสารละลายเกลือแกงเข้มข้น 1.5 และ 3.0 เปอร์เซ็นต์ โดยน้ำหนักไม่มีผลต่ออัตราการอบแห้ง ค่าสัมประสิทธิ์การแพร่ความชื้นมีค่าเป็น 5.57×10^{-10}, 6.94×10^{-10} และ 1.11×10^{-9} เมตรกำลังสองต่อวินาที ที่อุณหภูมิ 55, 65 และ 75 องศาเซลเซียส ตามลำดับ

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