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Quality Changes of Red Pitaya (*Hylocereus undatus*) Slices Dried in Hot Air, Microwave-Hot Air and Microwave-Vacuum Dryers

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Abstract: Quality changes of red pitaya (*Hylocereus undatus*) slices dried in hot air, microwave-hot air and microwave-vacuum dryers were investigated. The quality parameters were colour, water activity, shrinkage, rehydration ratio, ascorbic acid content and visual market quality. Microwave-vacuum produced pitaya with the best quality compared to hot air and microwave-hot air. Pitaya dried in microwave-vacuum had the highest rehydration ratio while the other methods presented similar rehydration ratios. Ascorbic acid in dried pitaya was also better retained when drying by microwave-vacuum. Apart from that, the drying time of pitaya dried in microwave-vacuum could be reduced by 83% compared to hot air.

Key words: Dragon fruit · Drying kinetics · Microwave convective drying · Microwave vacuum drying · Product quality

INTRODUCTION

Pitaya (*Hylocereus*) fruit is also known as dragon fruit due to the dragon-like appearance of the scales or bracts on its skin [1]. Pitaya is favoured fruit especially in Asian countries such as Vietnam, Taiwan, Malaysia and Philippines. Three commercial varieties of pitaya are *Hylocereus undatus* (Red Pitaya) which has red-skinned fruit with white flesh, *Hylocereus polyrhizus* which has red-skinned fruit with red flesh and *Hylocereus megalanthus* (Yellow Pitaya) which has yellow-skinned fruit with white flesh [2]. Peeled fruit slices are amongst the favoured after dinner desserts. It contains highly gelatinous carbohydrates such as cellulose, hemicellulose and simple saccharide polymers [3]. The flesh is mildly sweet. It is also converted into juice or used to flavour other beverages [4]. Many researchers have reported that pitaya fruit contains other antioxidant nutrients such as phenolic compounds and ascorbic acid, in addition to vitamin C which significantly contribute to its total antioxidant capacity [5-7].

Fresh fruits and vegetables contain a great deal of water and are rich with nourishment, which stimulates the growth of microorganisms resulting in putrefaction. Drying would remove the water within fruits and vegetables by evaporation of most of the water in the product. The reduction of moisture content inhibits or decreases microbial and enzymatic activity, being advantageous to dry long-term conservancy of the ware. But the drying process suffers from quality losses regarding colour, flavour and nutrient content and rehydration is often poor. Case hardening and shrinkage

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are the main problems. In recent years, improvement of quality retention by dried products, by altering drying methods and/or process conditions, has been a major research goal [8].

Hot air drying is a conventional process used to preserve foods in which the solid to be dried is exposed to a continuously flowing hot stream of air where moisture evaporates. The phenomena underlying this process is a complex problem involving simultaneous mass and energy transport in a hygroscopic, shrinking system. Air-drying offers dehydrated products that can have an extended shelf life.

The efficiency of drying process increases with the arising of air temperature as it enhances the effectiveness of moisture diffusivity [9, 10]. However, this process also negatively impacts product quality, due to the long drying times and high temperatures employed. The quality of the dried product is often lower than that of the original foodstuff, with an impact on colour, rehydration ratio, texture and other characteristics [11, 12].

Microwave drying has gained popularity in food preservation industries due to the shorter drying time, improved product quality and flexibility in producing a wide variety of dried products. The energy absorption level is controlled by the wet products which can be used for selective heating of interior parts of the sample containing moisture and without affecting the exterior parts. Microwave energy combined with other drying methods can improve the drying efficiency as well as the quality of food products which is far better than that achievable by microwave drying only or by other conventional methods [13, 14].

Microwave assisted air drying is one of the methods where hot air drying is combined with microwave heating in order to enhance the drying rate. For drying of high moisture fruits and vegetables, a reduction in moisture content is time consuming especially in the final stage of drying. Microwave assisted drying as final stage of air drying overcomes these disadvantages with high thermal efficiency. Hot air drying does not improve moisture loss at the final stages of drying process, since the diffusion process is very slow. Besides increasing the drying rate, microwave assisted air drying enhances the rehydration capacity of dried products and also overcome shrinkage problems [13].

In the absence of convection, either conduction or radiation or microwaves can be combined with vacuum drying to improve its thermal efficiency. During vacuum drying, high energy water molecules diffuse to the surface and evaporate due to low pressure. Because of this, water vapour concentrates at the surface and the low pressure causes the boiling point of water to be reduced. Thus vacuum drying prevents oxidation due to the absence of air and thereby maintains the colour, texture and flavour of the dried products [14]. Microwave vacuum drying is applied for heat sensitive materials such as banana, carrot, potato, etc. The loss of nutritional qualities (vitamins, α and β-carotenes etc.) of food products by microwave vacuum drying is minimized due to non exposure of heat and oxygen [13].

The selection of the proper drying method can affect the final product quality and the drying economics [15]. The aim of this study was to evaluate the effects of different drying methods on the drying of red pitaya slices based on the drying parameters such as drying time, final moisture content and drying rate. Quality parameters such as changes in colour, water activity, shrinkage, rehydration capacity, ascorbic acid content and visual market quality were also compared.

MATERIALS AND METHODS

Materials: Ripe red pitaya (*Hylocereus undatus*) used in this study were purchased at a local store. These fruits were imported from Vietnam into Canada by Canada Herb, Toronto, Ontario. Before each experiment, the fruits were hand peeled and cut into cylinders of 3.5 cm in diameter and 1 cm thick. The fresh red pitaya fruits used for the drying trials were without visual sign of physical damage, disease or physiological disorders. The mean fruit mass was 576.5 ± 54.7 g and, on average, moisture content was 84.4 ± 2.6% wet basis. The colour of fresh red pitaya fruits, defined in terms of mean L^*, a^* and b^* values, were 45.6 ± 1.7, 38.3 ± 3.2 and 10.1 ± 1.9, respectively; for the purple red skins' color, while the white flesh's colour were 63.7 ± 3.6, -0.32 ± 0.1 and 3.8 ± 0.4. The mean of total soluble solid content for fresh fruits was 12.33 ± 1.06 °Brix, while their ascorbic acid content was 1.88 mg g^{-1} F.W.

Drying Methods

Hot Air Drying: A laboratory constant temperature and humidity chamber made by Jeio Tech. Co., Ltd (Korea) was used for the hot air drying trials. Hot air flowed through the bed at 45% relative humidity. Temperature of the hot air was controlled at 55 °C. Before starting the drying process, the dryer was run for 30 minutes to achieved steady-state conditions. The fruit slices were placed in a holder suspended in the centre of the oven cavity and attached to the analytical balance. Sample mass, air and sample temperatures were monitored and recorded at regular time interval. The samples were dried until they reached the final moisture content.

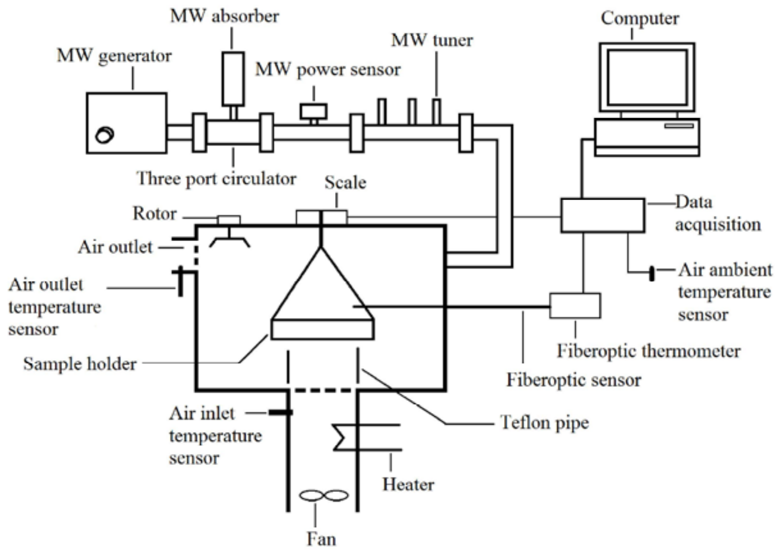

Fig. 1: Schematic diagram of microwave-hot air drying

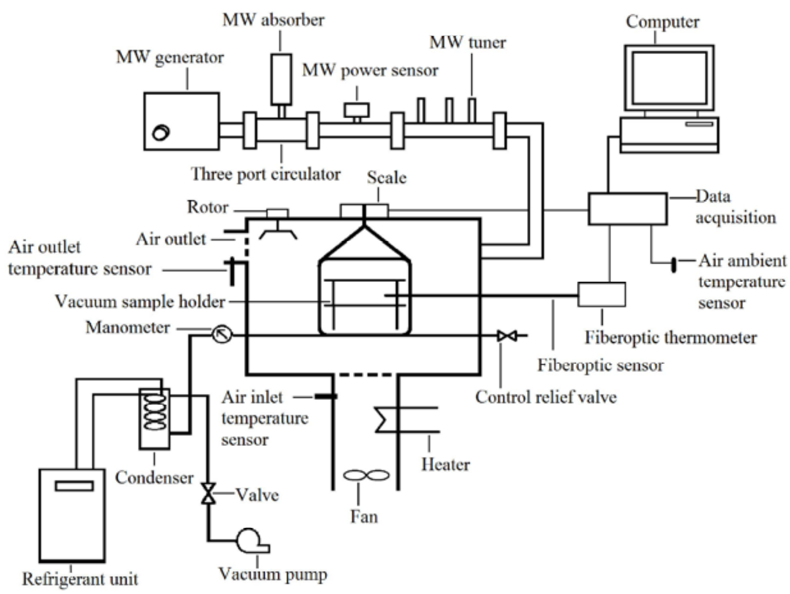

Fig. 2: Schematic diagram of microwave-vacuum drying unit

Microwave-Hot Air Drying: Microwave-hot air drying trials were performed using a laboratory scale drying unit at McGill University, Canada (Figure 1). It consisted of a 400 W microwave generator operating at 2,450 MHz, a three-port circulator, a microwave tuner, power meters, waveguides, a microwave absorber, a cavity and a data acquisition and controlled system. The dimension of the cavity was 490 mm by 250 mm by 380 mm. A motorized rotor was placed in the cavity to help distribute the microwave energy. Heated air was introduced into the cavity through a circular opening (diameter of 20 cm) made at the bottom of the cavity. A perforated metal grill was placed on the opening to prevent leakage of microwave. The sample holder consisted of a Teflon frame with a fine mesh screen. The holder was suspended to the load cell and located in the centre of the cavity. A microwave leakage detector model SMW-1, Microcheck (China) was used to detect any potential leakage. Agilent VEE Pro 8.0™ was used to control the data acquisition system (Agilent model 34970A) and to monitor and record all process parameters. A fiber optic sensor (Emi-TS Series, Nortec Fibronic Inc., Quebec, Canada) was used to monitor product temperature during the drying process. The red pitaya slices were subjected to drying at temperature of 55 °C and microwave power density of 1 W/g.

Microwave-Vacuum Drying: Modifications were made to the microwave-hot air dryer to allow it to operate under vacuum. These modifications consisted of the addition of a vacuum pump, a digital vacuum gage, a condenser an airtight sample holder and a control relief valve (Figure 2). The vacuum was maintained in the sample holder with a belt driven Boekel Hyvac vacuum pump model 91308-001. The control relief valve was set to maintain a vacuum of 6.67 kPa absolute in the sample holder. A condenser cooled to -15°C with ethylene glycol was placed between the sample holder and the vacuum pump to capture water vapor. A Fisher Scientific Isotemp 1013S cooling unit was used to cool down and circulate the cooling liquid in the condenser. The sample holder consisted of a polycarbonate bell jar mounted on a polypropylene base and of Teflon™ trays. All drying trials were performed with microwave power level of 1 W/g of fruits.

Drying Kinetics: The experimental results from this work are presented as drying curves. Drying curve was constructed from the variation of moisture ratio (MR) as a function of time t. The moisture ratio shown in Eq. (1) was used so that the resulting drying curves for all of experiments are comparable [16]:

$$MR = \frac{X - X_{eq}}{X_o - X_{eq}} \quad (1)$$

where X_o is the initial moisture content and X_{eq} is the equilibrium moisture content. However, in this study, the equilibrium moisture content was relatively small compared to X or X_o and nearly approached the dry matter content, thus appearing negligible. This approximation was also used by Celma *et al*. [17] where they simplified the equation to:

$$MR = \frac{X}{X_o} \quad (2)$$

Quality Assessment

Colour: The product quality in terms of colour was determined by measuring the colour change before and after drying by using a Minolta Chromameter CR-300 (Konica Minolta, Japan). The colour testing method used was CIE-$L^*a^*b^*$ method where L^* stands for lightness and a^* and b^* stand for chromaticity. The sign of a^* and b^* indicate colour direction: $+a^*$ is the direction to red, $-a^*$ is direction to green, $+b^*$ is direction to yellow and $-b^*$ is direction to blue [18]. The colour change, ΔE, is given by the following equation:

$$\Delta E = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2} \quad (3)$$

where

$$\Delta L^* = L^* - L_o^* \quad (4)$$

$$\Delta a^* = a^* - a_o^* \quad (5)$$

$$\Delta b^* = b^* - b_o^* \quad (6)$$

Water Activity: The water activity of fresh and dried red pitaya slices was measured room temperature using a water activity meter (AquaLab, Model Series 3TE, USA).

Shrinkage: Shrinkage caused by the drying process was expressed in terms of changes in sample volumes and measured using a displacement method in toluene [19]. Shrinkage was calculated as follows:

$$\Delta V = 1 - \frac{V}{V_o} \quad (7)$$

where V is sample volume and V_o is initial sample volume.

Rehydration Ratio: Rehydration capacity of the dried samples was determined following the method recommended by the US Department of Agriculture [20, 21]. A 5 g sample of the dried material was weighed and placed in a 500 mL beaker containing 150 mL of distilled water. The beaker was then placed on a hot plate and covered with a watch glass; the water was brought to boiling point in 3 min and allowed to boil for an additional 5 min. The sample was then transferred to a 7.5-cm Buchner funnel covered with Whatman No. 4 ?lter paper. Water was drained from the material by applying gentle suction until the dripping from the funnel had almost stopped. The sample was then removed and weighed.

Rehydration ratio was calculated as the ratio of rehydrated sample to that of dehydrated sample. The coefficient of rehydration, *COR*, was calculated using the following equation [21]:

$$COR = \frac{m_{rh}(100 - X_o)}{m_{dh}(100 - X_{dh})} \quad (8)$$

where m_{rh} is the mass of rehydrated sample, m_{dh} is the mass of dehydrated sample, X_o is the initial moisture content and X_{dh} is the moisture content of dehydrated sample.

Table 1: Quality Index (QI) used to assess the overall quality of dried pitaya slices

Index	Quality	Description
1	Excellent	Very good overall appearance, uniform drying, no colour change.
2	Good	Good appearance, less uniform drying, slight colour change.
3	Fair	Fair appearance, some slices are either over or under dried, browning becoming visible.
4	Poor	Poor appearance, more slices are either over or under dried, more intense browning of some slices.
5	Unsalable	Bad appearance, many slices are either over or under dried, intense browning of slices.

Ascorbic Acid Content: Ascorbic acid was measured by titration method, using phenolindo-2, 6-dichlorophenol (DPIP) as also used by Sahlin *et al*. [22]. The quantity of the ascorbic acid in the pitaya samples was then calculated using the following equation [23]:

$$\frac{\text{mg of ascorbic acid}}{\text{100 g fresh weight}} = \frac{(\text{sample} - \text{blank}) \times \text{dye factor} \times 100}{\text{sample mass} \times \text{aliquot}} \quad (9)$$

where

$$\text{dye factor} = \frac{\text{volume of ascorbic acid}}{0.5} \quad (10)$$

Quality Index: Sensory evaluation of a product, though subjective, is an important part of quality evaluation since it represents the same procedure that would be used by a consumer [24]. This analysis has been employed by Sunjka *et al*. [25] and Beaudry *et al.* [24] for dried cranberries, each had different sensory characteristics and its evaluation scale. In the present study, the appearance of the dried product was evaluated with a Quality Index (QI) scale ranging from 1 (highest quality) to 5 (lowest quality) as presented in Table 1.

Dielectric Properties: Dielectric properties of the samples were measured with an Agilent Network Analyzer model 8722ES (USA) equipped with an open-ended coaxial probe (model 85070D). Before the measurements, the instrument was calibrated using three different loads: air, short-circuited and distilled water at 20°C. The dielectric properties of the pitaya samples were measured by touching the surface samples with the flat face of open-ended probe.

RESULTS AND DISCUSSION

Drying Kinetics: The drying curves (moisture ratio versus time) of red pitaya slices dried by hot air drying, microwave-hot air drying and microwave vacuum drying are presented in Figure 3. It was clearly observed in Figure 3 that the difference on the drying time of red pitaya slices dried using different drying methods was significant. Drying time to 10% moisture content (db) for hot air drying was about 12 h, longer than drying using

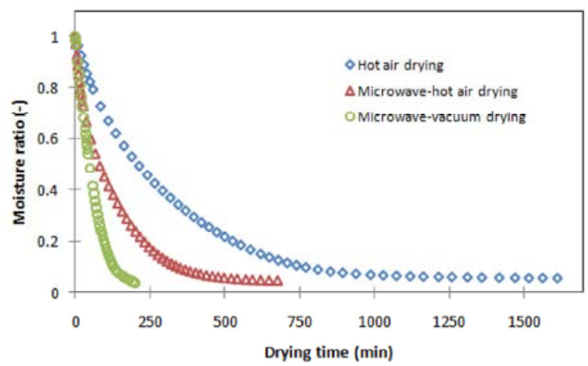

Fig. 3: Drying curves of red pitaya slices

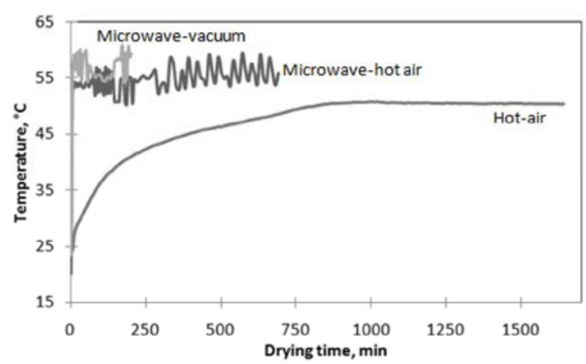

Fig. 4: Product temperature progressions during drying process

microwave-hot air and microwave-vacuum. It took only about 2 h for microwave-vacuum to dry the red pitaya slices, while drying in the microwave-hot air dryer required 6 h. The addition of the microwave energy to the hot air drying process enabled the drying time to be reduced by more than 50%. However, the drying time was reduced about 83% after application of a vacuum into the drying system. Similar result was obtained by Therdthai and Zhou [26] and Giri and Prasad [27] for the microwave vacuum drying and convective hot air drying of mint leaves and mushroom, respectively.

Temperature Progression During Drying Process: A comparison of the progressions of product temperature for hot air drying, microwave-hot air drying and microwave-vacuum drying (Figure 4) clearly indicated that the sample dried in the hot air dryer did not achieved

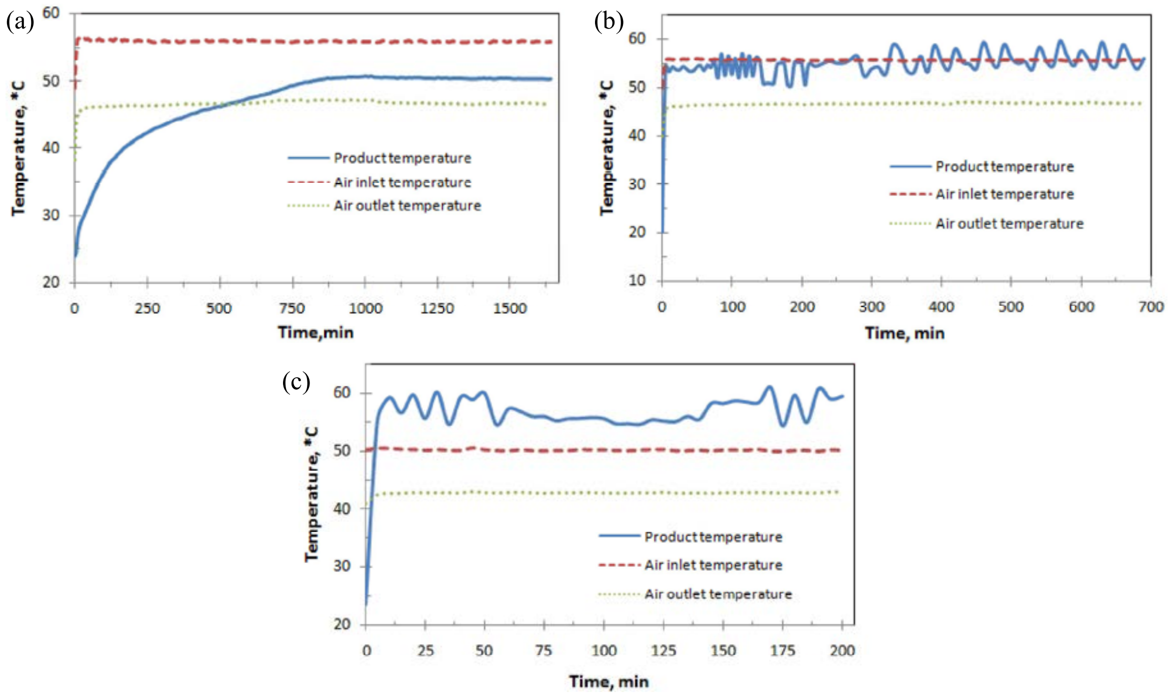

Fig. 5: Air inlet, air outlet and product temperatures progressions during: (a) hot air drying, (b) microwave-hot air drying and (c) microwave-vacuum drying

the set temperature of 55°C over the entire drying time of 27 hours. However, the product temperature of microwave-assisted drying (hot air and vacuum) immediately increased from the ambient temperature to the set temperature. Under these drying conditions, the product temperatures were maintained at the target temperature with the contribution of microwave energy.

The progression of air inlet, air outlet and product temperature during drying of red pitaya slices is shown in Figure 5. With the air inlet temperature of the unassisted hot air drying process set at 55°C, the product temperature slowly increased until it achieved a constant temperature (Figure 5a). However, the product temperature was still below the set points of about 50°C even though the system was run more than nine hours at the steady state temperature. This indicated that the heating process of hot air drying began from the surface of the samples.

The progression of air and product temperature of pitaya slices dried in microwave-hot air shown in Figure 5b, illustrates that product temperature was about the same as air inlet temperature (55°C) and higher than the in hot air alone. This occurred because the sample absorbed the microwave energy during the drying process to maintain the product temperature at the set point and the microwave was switch on only when the product temperature was below the set temperature. With this system, the product temperature was more uniform compared to the hot air drying system with no microwave assistance.

For the microwave-vacuum drying, the product temperature was fully controlled by the microwave energy applied to the system (Figure 5c). The air inlet temperature was set at 50°C to prevent condensation on the inside surface of the vacuum sample holder as previously mentioned.

Product Quality of Dried Pitaya: The quality attributes of red pitaya slices dried under hot air, microwave-hot air and microwave-vacuum drying are presented in Table 2. It was shown that the value of quality index of pitaya samples dried under microwave-vacuum was higher than the other two drying systems. Besides that, the pitaya slices dried in the microwave-vacuum drew up more water during the rehydration procedure than samples dried under the other systems.

Colour is one of the most important criteria for acceptability of a food. Undesirable changes in the colour of a food may decrease its quality and marketing value [15]. Table 2 shows the total colour changes of red pitaya slices dried in different drying methods. The least colour change was observed in the microwave-vacuum dried product because of the vacuum condition during the drying process and the shorter drying time.

Table 2: Quality attributes of red pitaya slices dried under hot air, microwave-hot air and microwave-vacuum

	Hot air	Microwave-hot Air	Microwave-vacuum
Quality index	1.2	1.2	2.0
Total color changes, ΔE	8.57	7.52	6.41
Water activity	0.423	0.431	0.462
Shrinkage (%)	84.73	85.57	81.04
Rehydration ratio	0.282	0.257	3.424
Ascorbic acid (mg g^{-1} FW)	0.212	0.685	0.838

The water activity of all dried pitaya samples was found to be lower than 0.7, which is often referred to as the limit for intermediate moisture foods. According to Beaudry *et al*. [24], foods having a water activity a_w between 0.4 and 0.65 are considered as dried products, whereas those having a water activity between 0.65 and 0.75 represent intermediate moisture foods. As shown in Table 2, no significant difference was observed for the water activity of pitaya dried in hot air, microwave-hot air and microwave-vacuum drying methods. This was because all the samples were dried until reaching the same final moisture content. All the dried products had values of a_w of below 0.7 which indicates that the growth of molds, bacteria and yeast is not promoted and enzymatic reactions are not likely to occur [24].

The effect of drying method on the shrinkage of red pitaya is shown in Table 2. The shrinkage of samples were 84.73, 85.57 and 81.04% for hot air, microwave-hot air and microwave-vacuum drying, respectively. From this comparison, the shrinkage of product from the three drying methods was not much different. As shown also in Table 2, the rehydration ratio of red pitaya samples dried by hot air, microwave-hot air and microwave-vacuum drying were 0.282, 0.257 and 3.424, respectively. The highest rehydration capacity was found for the microwave-vacuum dried sample which could be related to the lower shrinkage data. Qing-guo *et al.* [15] pointed out that a less shrunk structure has higher capacity to absorb water when reconstituted.

Since ascorbic acid (vitamin C) is relatively unstable to heat, oxygen and light, its retention can be used as an indicator for the quality of dried products. Cui *et al*. [28] stated that the higher the temperature, the longer the drying time, the more loss of vitamin C in the dried fruits and vegetables. The ascorbic acid contents in the product dried by hot air, microwave-hot air and microwave-vacuum dryers are presented in Table 2. It was observed that no significant loss of ascorbic acid in the pitaya occurred during microwave-vacuum drying, with the retentions of ascorbic acid of 44.6%. Ascorbic acid in the dried pitaya sample was better retained when subjected to microwave-vacuum drying due to the shorter drying time.

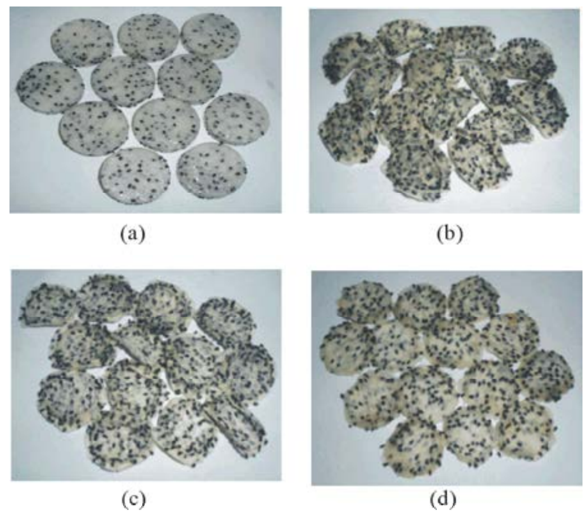

Fig. 6: Photographs of: (a) fresh pitaya slices, (b) hot air dried slices, (c) microwave-hot air dried slices and (d) microwave-vacuum dried slices

The lower ascorbic acid content in the dried pitaya samples for hot air and microwave-hot air drying was due to the oxidation and degradation of ascorbic acid in the presence of air.

The visual appearance of fresh red pitaya slices and of samples dried under hot air, microwave-hot air and microwave-vacuum drying is presented in Figure 6. Considerable reductions in size, as well as a slight darkening of the colour were observed in the dried product compared to the fresh samples. The darkening was more visible in hot air dried samples followed by the pitaya slices dried in a microwave-hot air. Dried product with the lightest colour was observed when drying under microwave-vacuum.

Dielectric Properties: The dielectric properties of materials vary with several different factors. In the present study, the dielectric properties of pitaya slices dried under the three different drying systems was measured and compared. Figure 7, which illustrates the relationship between dielectric constant (ϵ’) and dielectric loss factor (ϵ”) with shrinkage of pitaya slices at different moisture

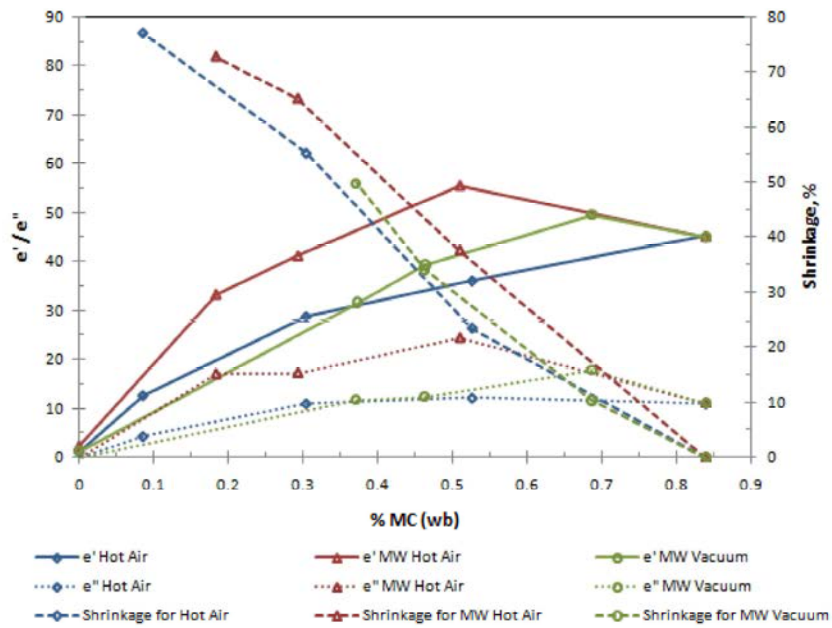

Fig. 7: Influence of dielectric constant (ϵ'), dielectric loss factor (ϵ") and volume shrinkage on the moisture content of red pitaya slices dried in three different drying systems: hot air dryer, microwave-hot air dryer and microwave-vacuum dryer

contents, clearly shows that the dielectric properties and shrinkage of pitaya slices obviously dependent on moisture content.

Moisture content is seen, as expected, to be inversely related to the shrinkage of red pitaya slices. However, shrinkage of dried pitaya slices was more pronounced under microwave-hot air drying compared to the other drying conditions. Different values of dielectric properties were obtained for dried red pitaya slices at the same moisture content for the different drying methods. This shows that dielectric properties and shrinkage of red pitaya slices also depends on the process applied to the samples and structure of the materials instead of just the moisture content as pointed out by Venkatesh and Raghavan [29].

In conclusion, fresh red pitaya slices were dried in three different drying systems: hot air dryer, microwave-hot air dryer and microwave-vacuum dryer. The addition of microwave energy to the hot air drying process enabled a reduction in drying time of over 50% compared to simple hot air drying; however, comparatively microwave-vacuum drying reduced drying time by 83% compared to simple hot air drying. The best product quality in terms of visual appearance was produced by microwave-vacuum drying. Microwave-vacuum drying was also able to retain 44.6% of the ascorbic acid content in the red pitaya fruit. Aside from visual appearance, rehydration ratio and ascorbic acid content, no significant differences in dried product quality were observed between the samples dried under hot air, microwave-hot air and microwave-vacuum drying.

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NOMENCLATURE

COR	coefficient of rehydration
db	dry basis
m	mass of sample
MR	moisture ratio
QI	quality index
V	volume of sampe
X	moisture content
ΔE	total colour changes
L^*	colour parameter
a^*	colour parameter
b^*	colour parameter
ΔV	volume shrinkage

Subscript

eq	equilibrium
o	initial
rh	rehydrated sample
dh	dehydrated sample