Optimization of Microwave-Convective Drying of Red Pitaya (*Hylocereus undatus*) Slices Using Response Surface Method

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Abstract

A laboratory scale microwave-convective dryer was designed and built to determine the effects of drying kinetics and quality attributes of red pitaya (*Hylocereus undatus*) slices. The drying conditions were optimized using the response surface method to arrange the combinations of three process parameters: microwave power density, thickness of Red Pitaya slices and the drying temperature of the product. The statistical analysis performed on the collected data revealed that the optimum conditions to dry red pitaya slices was at temperature of 55°C with an initial microwave power density of 1 W g^{-1} and a slice thickness of 7.5 mm. It took about 964 minutes to reduce the moisture content to about 10% (db). Slices dried under optimum conditions were then compared to slices of same thickness dried under hot air alone at the same temperature and it took about 2050 minutes to dry the slices to the same final moisture content.

Keywords: Drying kinetics, microwave, hot air, red pitaya, product quality.

Introduction

A pitaya (*Hylocereus*) is the fruit of several species of cactus, a medium- to large-sizes berry native to Central and South America (Nerd, *et al.* 1999; Hoa, *et al.* 2006). The red pitaya (*Hylocereus undatus*) fruit is one of the pitaya species characterized by red skin with white flesh, which is eaten raw, is delicate, mildly sweet and juicy. It contains numerous small soft black seeds and is low in calories. Freshly-harvested pitaya fruits are highly perishable, having a very short shelf-life, even under refrigerated conditions (O'Connor-Shaw, *et al.* 1994). Red pitaya requires some form of preservation in order to prolong their shelf-life.

Hot air drying is the most common drying method employed for food materials. However, major drawbacks are long processing times and changes in product quality. Combining microwave energy with a hot air drying system resulted in the removal by the air stream of moisture evaporated during microwave irradiation (Kudra & Mujumdar, 2002). Several investigators have reported that food materials can be successfully dried using microwave-convective drying techniques including grapes (Tulasidas, 1995), kiwifruit (Maskan, 2001), carrots (Prabhanjan, 1995), banana (Maskan, 2000), nuts (Silva, *et al.* 2006), chard leaves (Alibas, 2006).

The main purpose of this study was to investigate the potential benefit of using microwave-convective drying of red pitaya fruit slices. The process parameters studied were: the microwave power density, the thickness of the red pitaya slices and the drying temperature. At the end of drying, quality attributes were measured, compared and used to optimize the drying conditions using a response surface method.

Materials and Methods

Fresh pitaya fruits

Ripe red pitaya (*Hylocereus undatus*) fruits used in this experiment were purchased at a local store. These fruits were imported from Vietnam into Canada by Canada Herb, Toronto, Ontario. After their arrival, the fruits were stored in a walk-in cold room set at 10°C. Before each experiment, the fruits were hand peeled and cut into cylinders of 35 mm in diameter. The cylinders were then cut to the required slice thickness.

Microwave-convective drying system

The laboratory scale microwave-convective drying unit used in this study is presented in Figure 1. Heated air was introduced into the cavity through a circular opening (diameter of 200 mm) made on 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 program written in Agilent VEE Pro 8.0^{TM} was used to control the data acquisition system (Agilent model 34970A), and to monitor and record all process parameter.

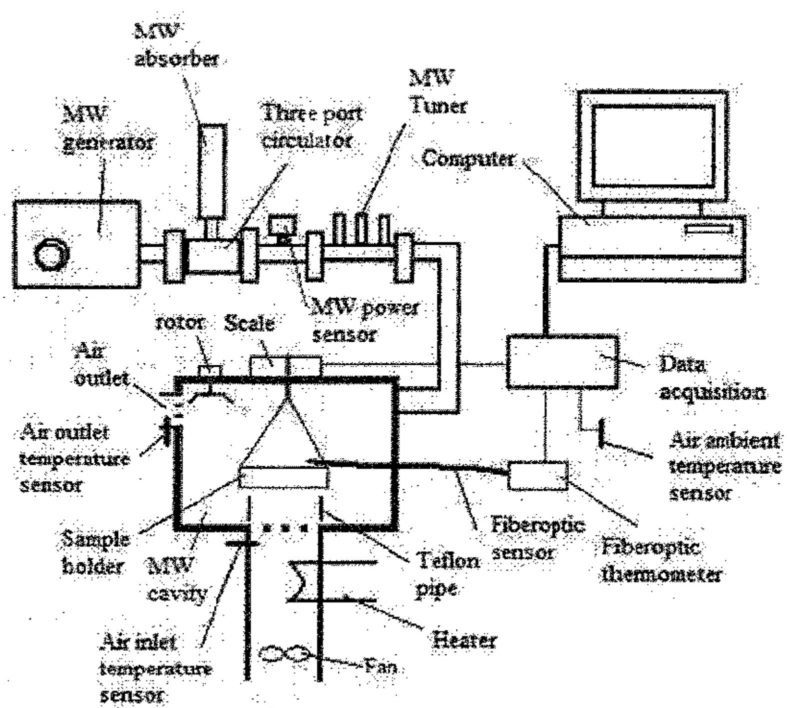


Figure 1. Schematic diagram of a microwave-convective dryer.

The drying conditions for this study were optimized using the response surface method. A central composite design with uniform precision was used to lay down the three process parameters: the microwave power density (W g^{-1}), the thickness (mm) of Red Pitaya slices and the drying temperature (°C). SAS 9.1 ADX Interface was used to set the combinations of factors between the maximum and minimum values (Table 1). In all, twenty combinations of factors were tested and the central point was repeated six times. The results were then used to optimize the process conditions for the best combination of the drying time (final MC of 10% (db)), product appearance and total color change.

Table 1. Factors levels used to study the drying kinetics of Red Pitaya slices under microwave- convective dryer.

Factor	Minimum level	Central point	Maximum level
Initial power density, W g^{-1}	0.5	1.0	1.5
Sample thickness, mm	5	10	15
Product temperature, °C	55	65	75

Contribution of microwave energy to the drying process

The contribution of microwave energy to the drying process was assessed by comparing the quality of pitaya slices dried under optimum conditions to slices dried at the same temperature in the same system under hot air with no microwave power. The criteria selected to compare the systems were: drying time to reach 10% MC (db), quality index, total color change, water activity, texture, shrinkage, rehydration ratio and ascorbic acid content. The experiment was run in triplicate and an analysis of variances was performed to determine if the observed differences were significant at the 0.05 level.

Moisture content and quality assessments

After drying, the residual moisture contents (MC) of the pitaya slices were determined by keeping the pitaya slices at 70°C for 72 hours in a convective hot air oven. Total soluble solids of the fresh samples were measured with Handheld Refractometer r^2mini Reichert Inc. (Japan) and expressed in °Brix. Appearance of the product was evaluated with a Quality Index (QI) scale ranging from 1 (highest quality) to 5 (lowest quality) and it is presented in Table 2.

Table 2. Quality Index (QI) used to assess the overall quality of dried red pitaya slices.

Index	Quality	Description
1	Excellent	Very good overall appearance, uniform drying, no color change.
2	Good	Good appearance, less uniform drying, slight color 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.

Sample colors were measured before and after drying with a Minolta Chromameter CR-300 (Japan). The color values were expressed in the CIE-L*a*b* (CIE 1976) color space and color change, ΔE, was as:

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

Water activity of the samples was measured using an AquaLab water activity meter Model 3TE (USA). Shrinkage caused by the drying process was expressed in terms of changes in sample volumes and measured using a displacement method in toluene (Tulasidas, 1994). Shrinkage was calculated as follows:

$$\Delta V = 1 - \frac{V}{V_o} \quad (2)$$

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

The texture of fresh and dry pitaya slices was measured with an Instron Universal Testing Machine Model 4500 (USA) equipped with a 50 N load cell. The puncture test consisted of driving through the samples, at a speed of 5 mm min^{-1}, a cylindrical probe of 3 mm diameter. The parameters recorded were the maximum force, the slope of the initial portion of the curve and the energy dissipated during the test.

Rehydration capacity of the dried samples was determined using a method recommended by the USDA (Anon, 1994). The rehydration ratio, *COR*, was calculated as:

$$COR = \frac{m_{rh}(100 - M_{in})}{m_{dh}(100 - M_{dh})} \quad (3)$$

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

Ascorbic acid was measured by a titration method, using phenolindo-2,6-dichlorophenol (DPIP) (Sahlin, *et al.* 2004). The quantity of the ascorbic acid in the pitaya samples was then calculated using the following equation (Ranganna, 2000):

$$\frac{\text{mg of ascorbic acid}}{\text{100 g fresh weight}} = \frac{(\text{sample} - \text{blank}) \times \text{dye factor} \times 100}{\text{sample mass} \times \text{aliquot}} \quad (4)$$

where,

$$\text{dye factor} = \frac{\text{volume of ascorbic acid}}{0.5} \quad (5)$$

Results and Discussions

Initial quality of pitaya fruits

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 587.6 ± 67.6 g and, on average, moisture content was 83.9 ± 2.6 % wet basis. Fresh red pitaya fruits' purple skin color, defined in terms of mean L*, a*, and b* values, was 45.2 ± 2.1, 38.9 ± 2.5, and 9.7 ± 1.0, respectively, while the flesh's color was 63.0 ± 3.4, -0.33 ± 0.08 and 3.7 ± 0.4. The total soluble solid content of the fresh fruits ranged from 9.7 to 13.7 °Brix and the mean ascorbic acid content was 1.88 mg g^{-1} F.W.

Drying time, final moisture content and product quality

Initial power density had no effect on drying time, final moisture content, quality index, total color changes, slopes of the texture loading curve, product shrinkage or rehydration ratio (Figure 2). On the other hand, increasing slice thickness resulted in longer drying time, more total color changes, and lower rehydration ratio. In addition, texture of the slices was affected by the initial slice thickness.

However, final moisture content was not affected by changes in slices thickness. Increases in thickness resulted in more energy being used to drive the punch through the samples and reductions in both the maximum force and slope recorded. Higher product temperatures during drying resulted in a decreasing final moisture content, deterioration of the product's appearance, with more colour changes and harder dried samples.

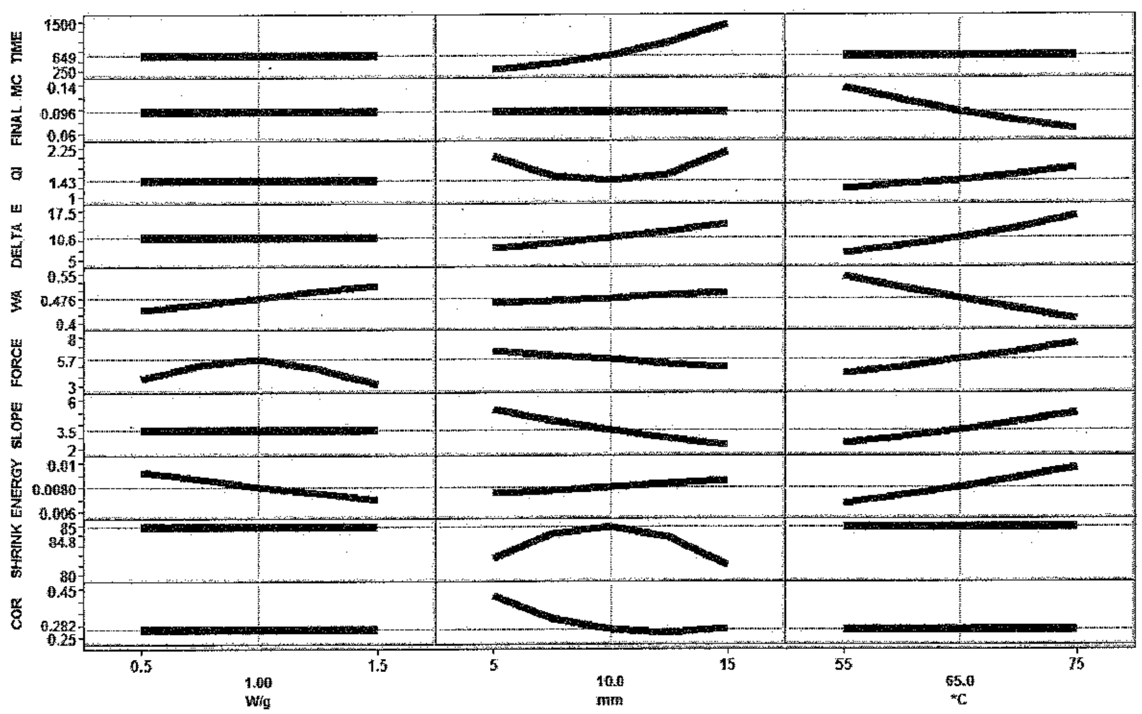


Figure 2. Graph generated with SAS ADX Interface showing the effect of process conditions on drying time, final moisture content and quality of dried red pitaya slices under microwave-convective dryer.

Optimization of drying process parameters

The parameters selected for the optimization of the drying process were: shorter drying time, best quality index and lower total color changes. Results from the SAS ADX Interface indicated that the best drying conditions for red pitaya slices were: an initial microwave power density of 1 W g^{-1}, a product temperature of 55°C and a slice thickness of 7.5 mm. Under these conditions, pitaya slices can be dried to 10% MC (db) in about 16 hours and the level of desirability for this condition was 92% (Figure 3).

Contribution of microwave energy to the drying process

The contribution of microwave energy to the drying process was measured by comparing the quality of pitaya slices dried under optimum conditions to those dried in the same system under hot air with no microwave power. As shown in Table 3, only differences in drying time and rehydration ratio were significant. The addition of microwave energy to the drying process permitted the reduction of drying time by more than 50%. It was also observed that pitaya samples dried under hot air alone drew up more water during the rehydration procedure than the samples dried under microwave-convective dryer.

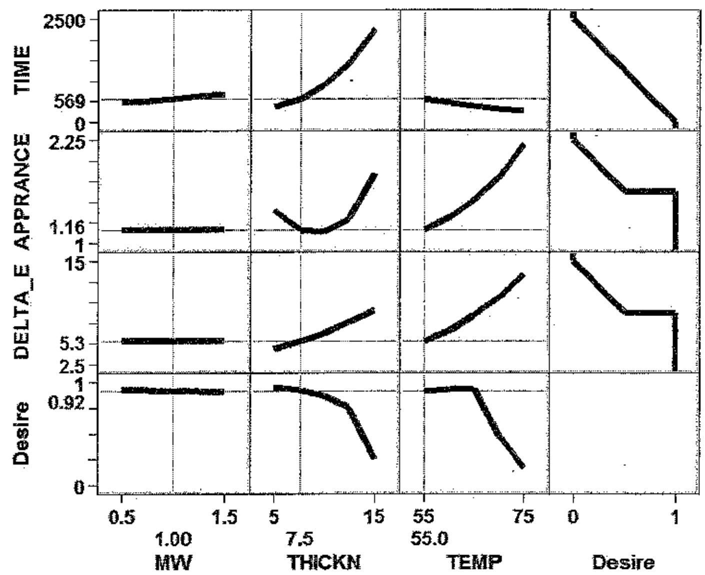


Figure 3. Optimization of process conditions for red pitaya slices dried in a microwave-convective dryer.

Table 3. Drying time and quality attributes of red pitaya slices dried under microwave-convective dryer and under hot air dryer alone.

	Microwave-convective	**Hot Air**
Time (min) reach at 10% MC (db)	*964.1 [b]	2056.8 [a]
Quality Index	1.2 [a]	1.2 [a]
Total color changes, ΔE	7.52 [a]	8.57 [a]
Water activity	0.431 [a]	0.423 [a]
Maximum force, N	4.49 [a]	3.87 [a]
Slope of the loading curve, N/mm	3.40 [a]	3.19 [a]
Energy, J	0.007 [a]	0.007 [a]
Shrinkage, %	85.6 [a]	84.7 [a]
Rehydration ratio	0.257 [b]	0.282 [a]
Ascorbic acid, mg g^{-1} F.W.	0.685 [a]	0.212 [a]

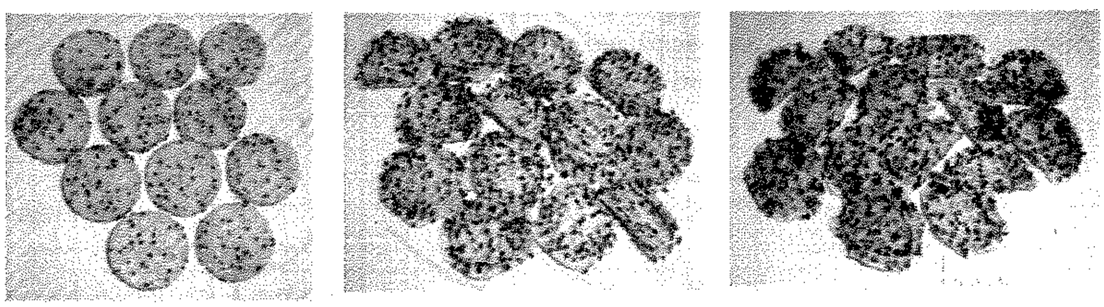
* Means in the same row and with the same letter are not significantly different at the 0.05 level.

Visual appearance of fresh and dried pitaya slices

Photographs showing the visual appearance of the fresh pitaya slices and of dried samples under microwave-convective and under hot air alone, are presented in Figure 4. Considerable reductions in size, as well as a slight darkening of the color were observed on the processed *vs.* fresh samples. The darkening was more visible on the hot air dried samples.

Conclusion

In this study, fresh red pitaya slices were dried in a microwave-convective dryer. The following conclusions could be drawn from the results:



(a) (b) (c)

Figure 4. Photographs of (a) fresh pitaya slices, (b) slices microwave-convective dried pitaya, and (c) slices hot air dried pitaya at optimal drying condition.

The use of a response surface method was effective in determining optimum process conditions: slice thickness of 7.5 mm, initial power density of 1 W g^{-1} and process temperature of 55°C. Under these conditions, pitaya slices can be dried to 10% MC (db) in about 16 hours.

When compared to hot air alone, the addition of microwave energy to the drying process permitted to reduce drying time by more than 50%. Aside from rehydration ratios, no significant differences in dry product quality were observed between samples dried at optimum conditions under microwave assisted hot air and under hot air alone.

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