

Osmotic Dehydration and Microwave Drying of Guava Fruit

Part 2: Microwave Convective and Microwave Vacuum Drying

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*The main objective of this study was to evaluate and compare two different drying methods of guava fruit (*Psidium guajava* L.) – atmospheric and subatmospheric, both involving microwaves (MW) as an energy source. This paper entails three components – MW and hot-air drying of guavas, MW and vacuum dryings of guavas, and comparison between these two. Osmotically-dehydrated guavas were microwave-dried using two temperatures of hot air (33°C and 43°C), two levels of MW mode (30 seconds on/30 seconds off, 30 seconds on/45 seconds off) and two MW power levels (40W and 50W). MW-vacuum part of the research tested two parameters – MW power mode (30 seconds on/45 seconds off and 30 seconds on/60 seconds off) and two power levels (50W and 60W). In subsequent comparison, several quality parameters were evaluated using two of the better methods of drying.*

Keywords: Fruit dehydration, guava, hot-air drying, vacuum-drying, water loss.

1. Introduction

The high water content of most fruits (over 80%) makes them highly perishable and is responsible for post-harvest losses in storage, handling and transportation, resulting in economic losses. Transformation to a stable product is thus necessary either by canning, freezing or drying.

The removal of moisture by MW-drying has five advantages over convective drying: fast and volumetric heating, higher drying rate, shorter drying time, higher quality of the product and reduced energy consumption [7]. It implies better fruit quality due to a lower growth of microorganisms. Lower temperatures and shorter drying times are usually required for a high quality product. Microwave-drying combined with vacuum has potential for high quality products, due to

a deeper penetration of microwaves into the tissues and a higher preference for water molecules.

However, the microwave-drying process can have very high capital costs. Several studies have shown that using pretreatments prior to microwave-drying could decrease drying time and thus drying costs [1,3,10]. Osmotic dehydration seems to be an efficient way to remove up to 50% of initial moisture [1]. It is desirable to combine microwaves with hot air because it improves both the efficiency and the economics of the process [13]. The role of microwaves is to heat the water molecules in the product and these molecules migrate from the interior to the surface of the product, whereas hot air is supposed to remove free water at the surface [7].

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The use of microwaves overcomes the problem of poor heat transfer in vacuum-drying. In microwave vacuum-drying, heat is generated in the tissues by the microwaves. The energy transfer rates in MW-assisted drying are much higher than in conventional drying operations, especially during the falling rate period.

The microwave-vacuum dehydration was first used for concentration of citrus juice by **Decareau** [2]. In the food industry, microwave-vacuum drying is used for drying of pastas, powders and porous materials. Since most pharmaceutical products are heat-sensitive and have high moisture contents (require intensive drying), microwave-vacuum drying is used by many pharmaceutical industries, mainly for the manufacture of tablet granulation [7].

McDonnell Company (McDonnell Aircraft Co., St. Louis, MO, USA) has built a microwave-vacuum-drying system (MIVAC®) to dry grains, but it was not commercially successful due to economics. One way to evaluate the feasibility of the microwave-drying is to calculate the drying efficiency [11]:

$$DE = \frac{t_{on} \cdot P \cdot (1 - m_f) \cdot 10^6}{M_i \cdot (m_i - m_f)} \quad (1)$$

DE = drying efficiency (MJ/kg water evaporated)

t_{on} = total power-on time (s)

P = microwave power input (W)

M_i = initial mass (kg)

m_i = initial moisture content (fraction)

m_f = final moisture content (fraction).

Operating pressure and microwave power level must be accurately chosen. **Drouzas** and **Schubert** [3] showed that increasing of pressure or microwave power level reduced the final quality of dried banana slices. However, the drying rate was significantly raised with increased microwave power level and reduced pressure. **Wadsworth et al.** [10] found that the drying efficiency of parboiled rice increased when MW power increased and the absolute pressure decreased. Total drying time has been found to be shorter when a lower pressure was used while drying cranberries [11].

Many comparisons have been made between microwave-vacuum drying and other systems, mainly hot air and freeze-drying. The dehydration rate for

MW-vacuum-drying is always faster. It took 33 minutes to dry carrot slices from 91.4 % to 10 % (moisture content, wet basis) with microwave-vacuum, although 8 hours and 72 hours were necessary to dry them with hot air and freeze-drying, respectively [4]. With regard to the final quality of the dried product, microwave-vacuum drying is comparable to freeze-drying and much better than conventional air-drying [1]. Microwave-vacuum-dried cranberries were also redder and had a softer texture than those dried with hot air [12].

One way to counter disadvantages of MW drying, such as the loss of aroma or physical damage (burning), is to use a pulsed mode. This alternates power-on and power-off time. It permits redistribution of the temperature and the moisture profiles within the product during off-times. For a given product, microwave power-on time and pulsing ratio should be optimised.

There are insufficient studies in this field concerning tropical fruit, like guava. Therefore, the main object of this paper is to evaluate and optimise process parameter for drying of guava fruit using MW convective drying and MW vacuum drying. Finally, the comparison between two best combinations of each of these two drying methods is made. The aim is to obtain a guava with low water activity of below 0.7, which is resistant to microbial growth and enzymatic reactions [8].

2. Materials and Methods

2.1 Pretreatment of Guavas

White-flesh guavas of unknown cultivar from Brazil were obtained from a local fruit retailer. The fruits were cut into 4 mm-thick slices and first dehydrated through osmosis by putting them in High Fructose Corn Syrup (HFCS, 76°Bx, Van Waters and Rogers Ltd, Canada) at a 2:1 fruit to sugar ratio at ambient temperature ($23 \pm 1^\circ\text{C}$) for 18 hrs, as it was determined in the first part of this paper. Ascorbic acid (Hebei Welcome Pharmaceutical Co. Ltd, China) was added to the osmotic solution at a concentration of 1% (mass %), in order to prevent the fruit pieces from browning.

After osmotic dehydration, the guava slices were rinsed with warm tap water to remove the adhering solution and gently dried with an absorbent paper towel. Then, the quality measurements were

done: water content by drying in an oven (Cole-Parmer Instrument Company) at 70°C until the sample mass became constant, water activity (method described in the Section 2.4), colour (method described in the section 2.4), and texture (as toughness, method described in the Section 2.4). Dehydrated guavas were stored in a fridge at 4 °C for one week until used for drying. Initial moisture content (the mean of four samples – three replicates) of fresh guavas averaged 83.9%; it was reduced to 57% (the mean of four samples) after osmotic dehydration.

2.2 Microwave Unit

A laboratory-scale microwave oven (**Figure 1**) was modified and used to perform the tests. Microwaves were generated by a 750W, 2450 MHz microwave

generator (1), whose power could be modulated, and travelled through rectangular wave-guides (2) to the microwave cavity (3). 50±2 g of guava slices (between four and six slices) were put in one layer on a sample holder (4) whose mass was recorded during the drying process with a strain gauge (5).

A circulator (6) ensured the absorption of reflected microwaves within the main cavity and tuning screws (7) inserted in the top of the wave-guide assembly were used to maintain the reflected power close to zero during the process. A 0.25 kW blower (8) placed underneath the drying cavity continually blew air heated by 2 kW-electrical heaters (9).

Air velocity was measured with a wind meter (Kestrel, Vole-Parmer Instrument Company) and it remained constant at approximately 2 m/s throughout

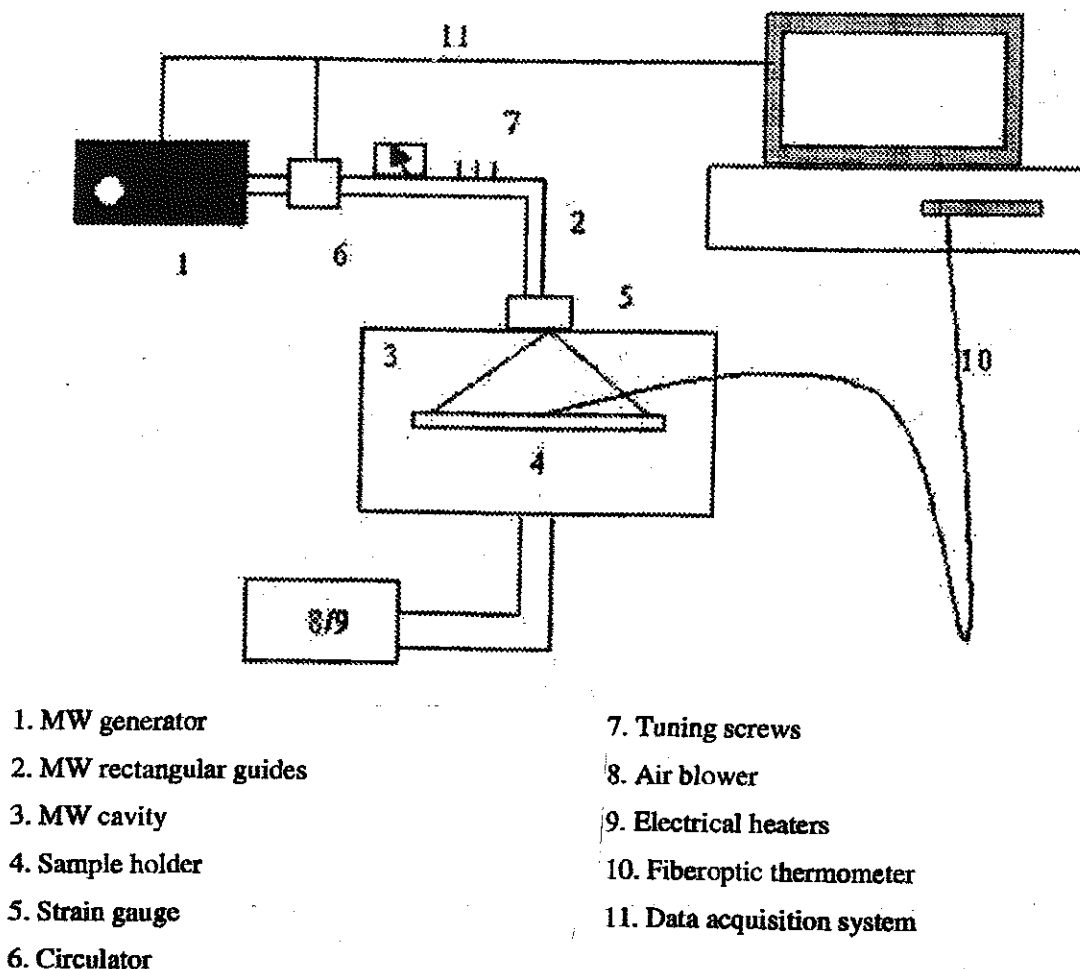


FIGURE 1: Schematic of the Hot-Air Microwave Unit

the tests. Temperature was set at either 33°C or 44°C but also constant during the drying process (by using air heaters located at the entrance to the microwave chamber). The inlet and outlet air temperatures were measured with Type-T thermocouples and the one for the samples measured with an appropriate microwave-resistant thermometer made from optic fibre (Fisher Scientific, Canada) (10).

Temperature, mass and power were recorded by a data acquisition system (HP34970A-data Acquisition, Switch Unit, Hewlett-Packard, USA). A computer programme written in HPVEE monitored and controlled the drying process (mass recording, power measuring, turning power on/off). It must be noted that a feedback (11) stopped the generator if the reflected power was too high (more than 50% of the incident power), in order to protect the generator from excessive reflected power. The samples were left in the cavity until they reached the mass corresponding to the desired moisture content. They were stored at 15°C refrigerator until quality evaluation was performed.

For the microwave-vacuum part of the experiment, the same unit was used, without heated air and a thick-walled glass container replaced the holder. A vacuum pump (John Scientific Inc., Canada) evacuated the space within the container. The pressure level remained constant within the experiments between 1 and 2 kPa of absolute pressure. A desiccator filled with anhydrous calcium sulphate, regularly replaced when saturated, captured the

moisture from the product. An optical fibre thermometer measured the sample temperature. The same weight of sample was used (50±2 g). A single layer of guava slices was placed on one side of the container, lying horizontally and slightly inclined. Preliminary tests helped to determine the duration of the drying.

2.3 Power Level, Power Mode and Temperature of the Hot Air

Three parameters were varied: power level, power mode (on/off) and temperature of the hot air. Preliminary tests showed that high power levels (greater than 60W) lead to burnt guavas. Therefore, low power levels were applied: 40 and 50W corresponding to 0.8 and 1W/g sample respectively for microwave-hot air-drying and 50 and 60W are corresponding to 1 and 1.2W/g sample for microwave-vacuum-drying.

Results of preliminary studies showed that continuous microwave mode is harmful for the fruits and therefore only pulsed mode was applied in this research. Different combinations were tried for each type of drying: 30 sec power-on/ 30 sec power-off; 30 sec power-on/ 45 sec power-off; and 30 sec power-on/60 s power-off. Two temperatures of the inlet air were tried: 33°C and 44°C.

Finally, four combinations were chosen for microwave hot air drying and three for microwave-vacuum drying to obtain acceptable dried guavas; these are listed in Table 1. All experiments were replicated

TABLE 1: Drying Method Combinations used in this Study

Drying Method	Name	Air Temperature (°C)	Power Mode (s on/s off)	Power Level (W)
Microwave Hot Air	T ₁	33	30/30	40
	T ₂	43	30/30	40
	T ₃	43	30/45	40
	T ₄	43	30/45	50
Microwave-vacuum	T ₁	-	30/45	60
	T ₂	-	30/60	60
	T ₃	-	30/45	50

three times. The dried guava slices were then subjected to an objective quality evaluation as described below. The most appropriate combination of power level, power mode and temperature based on quality was selected.

2.4 Quality Evaluation

Several quality parameters were tested, such as colour, rehydration ratio (coefficient of rehydration), water activity, and textural properties (toughness). Colour was measured in L^*a^*b coordinates, where L^* stands for the lightness (0 for black, 100 for white), a^* for the red-purple (positive values) to the bluish-green (negative values) and b^* indicates the yellowness (positive values) and blueness (negative values) [5], using a Minolta Chromameter Model CR-300X (Minolta Camera Co. Ltd., Japan). Two derived colour parameters – hue angle h° and Chroma value C^* were calculated using equations [5]:

$$h^\circ = \arctan\left(\frac{b^*}{a^*}\right) \quad (2)$$

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

Cranberry samples of 2.5 g were rehydrated by immersing in boiling water for four minutes. The samples were then transferred to a Buchner funnel covered with Whatman no. 1 filter paper, and surface moisture was removed by applying a gentle suction until no more drops were observed. Coefficient of rehydration was calculated using following equation [9]:

$$COR = 10 \cdot \left[\frac{m_{rh} \cdot (100 - M_{in})}{m_{dh} \cdot (100 - M_{dh})} \right] \quad (4)$$

Where:

COR = coefficient of rehydration (ratio),

m_{rh} and m_{dh} = mass of rehydrated and dehydrated sample, respectively (g), and

M_{in} and M_{dh} = moisture contents of the sample before and after drying, respectively (% wet basis).

Measuring of water activity is a non-destructive method, and was performed at 25°C using an Aqualab water activity meter 3 TE Series (Meyer Service & Supply, Ont., Canada). The textural properties (represented as toughness in kN) of guava samples were determined by using the Instron Universal Testing Machine (Series IX, Automated Materials Testing System 1.16). Statistical analysis of all parameters was done using Analysis of Variance (ANOVA). Differences were identified as significant or insignificant based on Duncan's multiple range tests for each variable. The significance level was 0.05 in all cases. Statistical analyses were carried out using Statistical Analysis Software (SAS) System, version 8.0.

2.5 Moisture Sorption Isotherm

As the purpose of the experiments was to obtain dried guavas with a water activity lower than 0.7, a moisture desorption isotherm was made experimentally at room temperature ($23 \pm 1^\circ\text{C}$) to determine the moisture content that should be reached for that purpose.

Slices of guavas were put into a drying oven (Cole-Parmer Instrument Company) at 70°C . They were removed from the oven at different times, left at room temperature for a few minutes and then water activity was evaluated. The pieces were placed back in the drying oven to continue drying, and at the end, their moisture content was determined. The moisture desorption isotherm is showed in **Figure 2**. The logarithm trend line fits with a coefficient of determination of 0.9839. With this equation, a water activity of 0.6 corresponds to a water content of 15.6%. Water activities obtained for each drying method (i.e., microwaves and hot-air, and microwaves and vacuum) can be seen in **Tables 2 and 3** respectively.

3. Results and Discussions

3.1 Microwave Hot-Air Drying

Sample moisture content and temperature during the drying process are showed in **Figures 3 and 4**, respectively. The two stages (constant rate and falling

TABLE 2: Mean Water Activity of Fresh, Dehydrated and Microwave Hot-Air-Dried Guava Slices

Method	a_w
Fresh	0.994 ^a
Osmotically-dehydrated	0.954 ^a
T ₁	0.669 ^b
T ₂	0.668 ^b
T ₃	0.667 ^b
T ₄	0.656 ^b

Means with the same letters are not significantly different.

TABLE 3: Mean Water Activity of Fresh, Dehydrated and Microwave-Vacuum Dried Guava Slices

Method	a_w
Fresh	0.994 ^a
Osmotically-dehydrated	0.954 ^b
V ₁	0.650 ^d
V ₂	0.653 ^{c,d}
V ₃	0.670 ^c

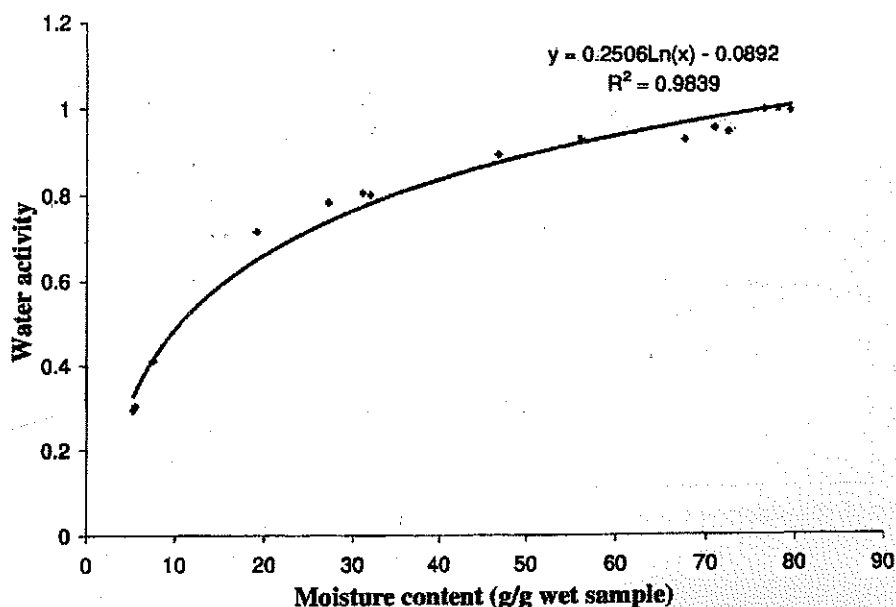
Means with the same letters are not significantly different.

rate) of the drying process can be observed in **Figure 3**. During the first 50 minutes, the moisture content of guava slices decreased constantly. This constant drying rate corresponds to the evaporation of free moisture from the surface. Then, the drying rate decreased because water transfer from inside was slower than evaporation from surface and this became the limiting factor.

It is important to mention that for all experiments, slices at a specific location (close to microwave inlet) on the sample holder tended to have a small burnt area, whereas the other slices were acceptable. That means that the possibility of a non-

uniform distribution of microwaves inside the cavity has to be considered. Using a rotating tray instead of an immobile sample holder might have resolved the problem.

Guavas are very sensitive to heat, as determined in preliminary trials. High power level or continuous mode can lead to burnt slices. Only one layer had to be used on the sample holder because browning and burning occurred as soon as the slices overlapped. As expected, water activity decreased with the drying process. Water activities of the dried products were a little higher than expected, with a mean of 0.66. However, a water activity below 0.7 indicates

**FIGURE 2: Graph of the Water Activity vs. Moisture Content of Guava Pieces**

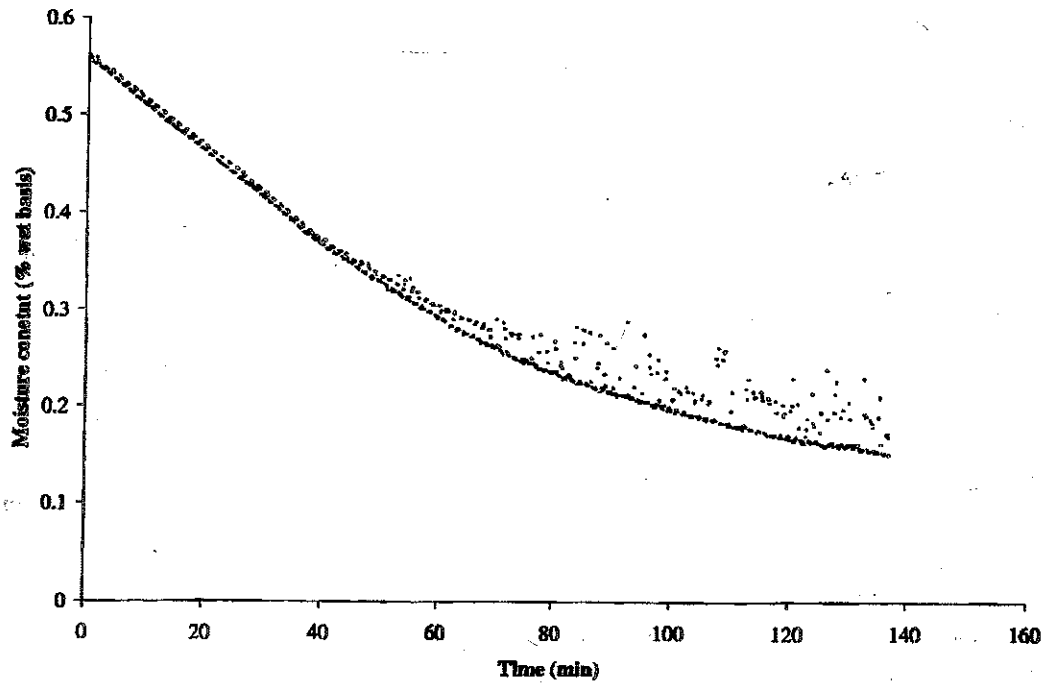


FIGURE 3: Graph of the Sample Moisture Content during Treatment T_3 of Microwave-Hot Air- Drying Process

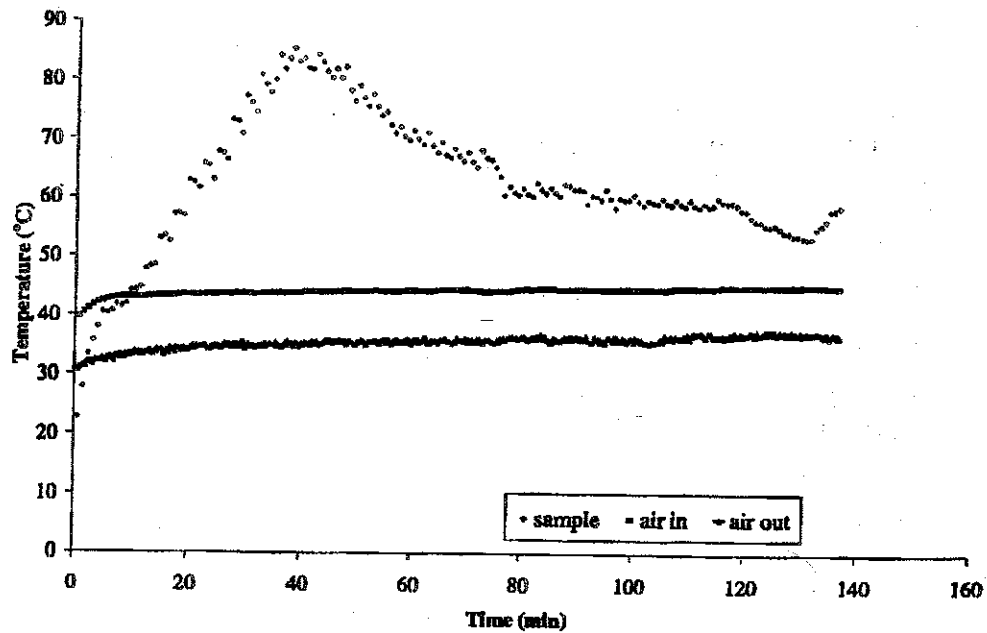


FIGURE 4: Graph of the Sample and Air Temperatures during Treatment T_3 of Microwave-Hot Air-Drying Process

TABLE 4: Mean Colour Values for Fresh, Dehydrated and Microwave-Hot Air-Dried Guavas

Method	L*	a*	b*	h(°)	C*
Fresh	80.75 ^a	-4.13 ^c	24.39 ^c	99.59 ^a	24.78 ^c
Osmotically-dehydrated	67.78 ^b	-0.90 ^b	27.40 ^b	91.88 ^b	27.42 ^{b,c}
T ₁	59.65 ^d	4.45 ^a	32.78 ^a	82.32 ^c	33.12 ^a
T ₂	65.88 ^{b,c}	1.17 ^b	29.56 ^b	87.83 ^b	29.60 ^b
T ₃	61.08 ^{c,d}	4.56 ^a	33.31 ^a	82.06 ^c	33.68 ^a
T ₄	61.09 ^{c,d}	4.51 ^a	34.04 ^a	82.39 ^c	34.35 ^a

Means with the same letters are not significantly different.

that the growth of mould, bacteria and yeast are prevented, as well as enzymatic reactions [8].

Mean colour values of dried guavas from both fresh and previously osmotically-dehydrated samples were compared. The data obtained are grouped in **Table 4**. As the fresh guavas used had a yellow flesh, the colorimeter showed a high L* (80.7) and a positive b* (+24.4). Both osmotic dehydration and drying process affected the colour values. When losing moisture, it was apparent that the guavas became significantly darker (L* decreased), redder (a* increased) and more yellow (b* increased). As both a* and b* increased, the saturation C* increased also.

The Duncan's grouping showed that the colour parameters L*, a*, b*, h° and C* of guavas obtained with the treatment T₂ were significantly different from those obtained with the three other treatments. These parameters showed no significant difference compared to guavas obtained only with osmotic dehydration. Therefore, it can be stated that T₂ method had a smaller effect on surface colour of guava slices. This may be attributed to the lower drying time, as T₂ is the combination with the highest overall power-on time.

TABLE 5: Coefficient of Rehydration of Guava Slices dried under Different Combinations with Microwave-Hot Air-Drying Process

Method	COR
T ₁	4.02 ^b
T ₂	4.02 ^b
T ₃	4.39 ^{a,b}
T ₄	4.83 ^a

Means with the same letters are not significantly different.

Toughness was used to compare texture of the dried samples. The results are showed in **Figure 6**. Toughness of fresh slices did not change after an osmotic treatment and the dehydrated guava slices remained very soft. However, toughness increased with the microwave-drying process. The combination T₂ seemed to be less effective as the toughness is not significantly different from the fresh and the osmotically-dehydrated slices.

Rehydration properties were not the same for all treatments. The coefficient of rehydration was significantly higher for the treatments T₃ and T₄ (**Table 5**) than for the others, although the toughness was higher. Rehydration properties were thus improved with higher power off time and higher power level.

3.2 Microwave-Vacuum-Drying

As it was observed during the previous experiments with microwave and hot air, non-uniform drying occurred, both inside the cavity and inside the vacuum chamber. The chamber had to be put off-centre inside the cavity, to minimise direct burning from microwaves. Due to the condensation and dropping of water inside the chamber, the slices at the bottom were more wet than the others, causing burnt spots due to high water content.

The temperature curves were similar for all experiments. As expected, the temperature of the sample increased during the power-on time and decreased during the power-off time. However, during the power-on time, the inside temperature rose higher, then it decreased during the power-off time so that from a larger time scale, the temperature increased steadily, until the temperature of 90°C was reached. (**Figure 5**).

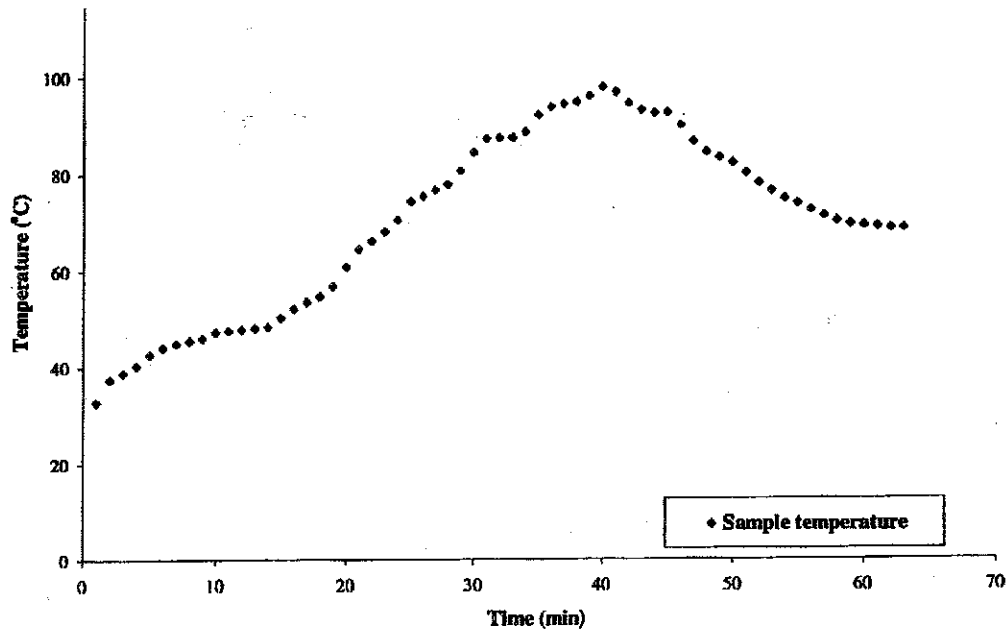


FIGURE 5: Graph of the Sample Temperature during Treatment V₂ of Microwave-Vacuum-Drying Process

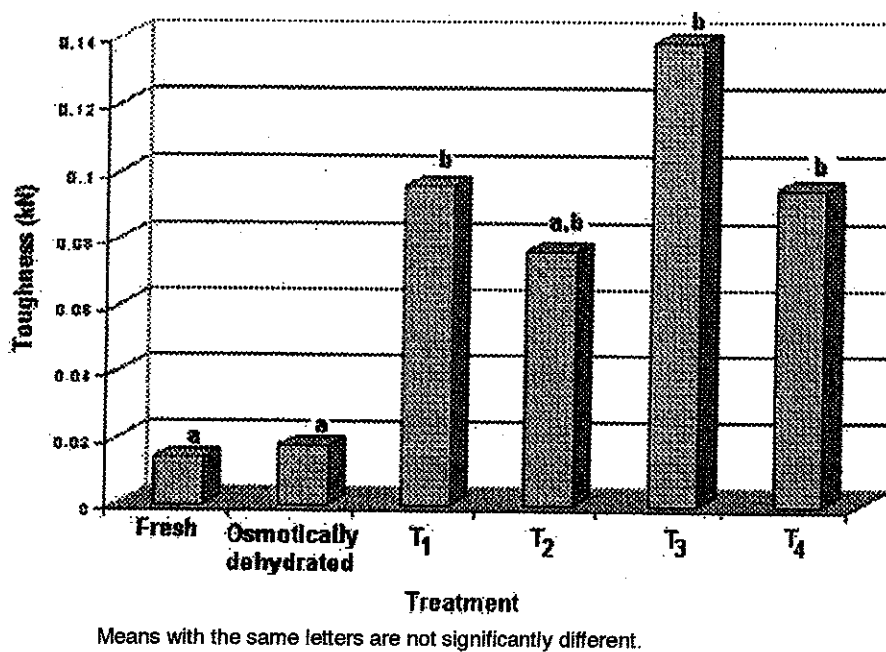


FIGURE 6: Graph of the Toughness of Guava Slices submitted to Different Combinations with Microwave-Hot Air-Drying Process

TABLE 6: Drying Time and Total Power on Time for the Three Combinations with Microwave-Vacuum-Drying Process

Method	Drying time (Min)	Total Power-On Time (Min)
V ₁	59.3 ^b	23.7 ^b
V ₂	68.8 ^a	22.9 ^a
V ₃	68.3 ^a	27.3 ^a

Means with the same letters are not significantly different.

Water activity of guava slices in each method decreased under 0.67 (Table 3), which is an indication of safe water content for good food safety. Mean colour values for guavas dried under different combinations, and for fresh and osmotically-dehydrated guavas. The data obtained are grouped in Table 6.

The drying process did not seem to have an influence on the lightness (L*) of guava slices among methods V₁, V₂ and V₃ as the L* value is not significantly different; it is even significantly higher than the osmotically-dehydrated guava slices' value in method V₁. However, the redness a* and the yellowness b* increased. Pink colour areas could effectively be observed on some slices for every treatment.

While comparing all combinations of power level/power mode, there exists only a slight difference for the chroma value (Table 7). The Duncan's grouping showed that the chroma of slices dried with treatment V₁ (60W, 30 sec power on/45 sec power off) had the highest C* value, due to a significantly higher yellowness b*.

Toughness was used to compare texture of the dried samples. The results are shown in Figure 7. Toughness became significantly higher with the drying process. Guava slices dried with treatment V₂ were

significantly tougher than the treatments V₁ and V₃. This is the sample that remained the longest (no different than V₃) in the cavity, though the total power-on time was the shortest (no different than V₁), as can be seen in Table 3.

Duncan's grouping showed no significant difference for the coefficient of rehydration of the sample dried with different combinations. The different combinations did not appear to have any influence on the rehydration capacity of guava slices.

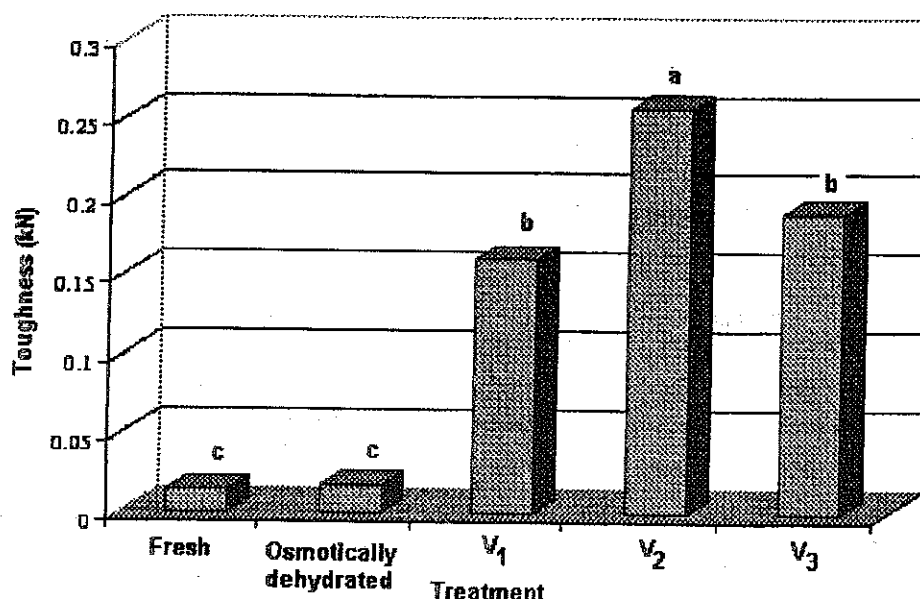
3.3 Comparison between Microwave-Hot Air and Microwave-Vacuum-Drying

The objective of this last section was to estimate which of these two processes is better by comparing two best treatments for microwave-hot air (T treatments) and microwave-vacuum-drying (V treatments). From the results, the treatment T₂ was significantly better than the others for almost all the observed parameters, such as colour and toughness. Concerning the microwave-vacuum treatment, although no large differences were found between the three treatments, V₃ was chosen for comparison only because of its closer b* value to the osmotically-dehydrated guava slices than the V₁ or V₂.

TABLE 7: Mean Colour Values for Fresh, Dehydrated and Microwave-Vacuum-Dried Guavas

Method	L*	a*	b*	h(°)	C*
Fresh	80.75 ^a	-4.13 ^b	24.39 ^d	99.59 ^a	24.78 ^d
Osmotically dehydrated	67.78 ^c	-0.90 ^b	27.40 ^c	91.88 ^b	27.42 ^c
V ₁	72.10 ^b	3.60 ^a	34.39 ^a	83.76 ^c	34.91 ^a
V ₂	68.76 ^{b,c}	7.38 ^a	31.16 ^b	76.68 ^c	32.02 ^b
V ₃	70.21 ^{b,c}	6.92 ^a	31.98 ^b	77.82 ^c	32.74 ^{a,b}

Means with the same letters are not significantly different.



Means with the same letters are not significantly different.

FIGURE 7: Toughness of Guava Slices submitted to Different Treatments with Microwave-Vacuum Drying Process.

With the exception of water activity and yellowness, all parameters are found to be significantly different, as seen in Table 8.

Regarding the colour properties, although lightness is significantly higher for the samples dried with microwave-vacuum, the other parameters of samples dried with microwave-hot air were closer to the properties of fresh guava slices. Toughness was also lower, but unexpectedly the rehydration capacity was significantly better for the slices dried with vacuum. This can be explained by better preservation of the fruit tissue during microwave-vacuum-drying, which can absorb more water in the rehydration process.

4. Conclusions

Because of the scarcity of microwave guava-drying experiments, comparison with previous works was not performed. Experiments were performed to evaluate dried guava slices (previously osmotically-dehydrated)

with combined microwave methods: either with hot air or with vacuum. Preliminary tests showed that high power level (more than 60W) in combination with continuous mode tended to burn the guava slices. Lower power settings were thus chosen (between 0.8 and 1.2 W/g sample and with pulsed mode). However, the non-uniformity of microwave-drying was a significant problem, which might be resolved with a rotating tray or moving belt.

For microwave-hot air-drying, a combination of 40W, 43°C and 30 sec power-on/30 sec power-off was found to be the most acceptable. 50W, 2 kPa of absolute pressure and 30 sec on/30 sec off was the combination that gave the closest quality of guava pieces to that of fresh fruits for microwave-vacuum drying process. Guava slices dried with the first method were more acceptable regarding colour and texture properties but rehydration properties were better for the slices dried with microwave-vacuum.

TABLE 8: Comparison between T₂ and V₃ Treatments for All Parameters

Method	a _w	L*	a*	b*	h(°)	C*	Toughness (kN)	COR
T ₂	0.667 ^a	65.88 ^b	1.17 ^b	29.56 ^a	87.83 ^a	29.60 ^b	0.0764 ^b	4.00 ^b
V ₃	0.667 ^a	70.21 ^a	6.92 ^a	31.98 ^a	77.82 ^a	32.74 ^a	0.1895 ^a	4.53 ^a

Means with the same letters are not significantly different.

The results showed that although microwave-vacuum-drying had shorter drying time (approximately 60 minutes against more than 90 minutes for microwave-hot air-drying), the colour and texture properties were less changed with microwave-hot air. However, rehydration capacity was better with vacuum. Further tests should be performed regarding the product quality, such as other rehydration properties (colour, texture) and a sensory evaluation. It should be noted that the numerous seeds remained a problem because they are inedible and they tend to harden after drying. Because of this, in all experiments, seeds were removed manually. Deseeding or cultivars with smaller seeds or seedless should be applied.

5. Acknowledgements

The authors would like to express their gratitude towards Natural Sciences and Engineering Research Council of Canada (NSERC) for the funding of this project to Mrs. Valerie Orsat and Mr. Yvan Garipey for their practical support during this study.

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