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MICROWAVE DRYING OF WHOLE, SLICED AND PUREED STRAWBERRIES

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ABSTRACT

Dehydration of whole, sliced and pureed strawberries (*Fragaria ananassa*) by convective air and microwaves (600 W oven) was investigated and compared to convection and freeze-drying. Tests were conducted at combinations of 10, 20, 30 and 40% duty cycles at inlet air temperatures of 30, 35 and 40 °C. The air velocity was constant at 2 m/s. In all tests, microwave drying was much faster than either of the other methods. Whole berries burst open and could not be dried in a microwave. Rehydration, chromacity measurements and panel judgement were performed to evaluate the quality of the dried slices and puree. The microwave-dried sliced and pureed berries were inferior to the freeze-dried berries in all categories.

Keywords: *Strawberries, microwave, drying, quality, convection*

1. INTRODUCTION

The strawberry is a very delicate and delicious fruit grown predominantly in temperate climates. It can be stored fresh for only 6-7 days, and is available for only a few months in the year. Seventy percent of the strawberries grown are sold in the fresh fruit market and the remainder are destined for the frozen and processed fruit markets (Perkins-Veazie and Collins, 1995). If dried, strawberries can be available throughout the year. Since strawberries have a high average moisture content of 89.9%, and because the waxy outer skin is highly resistant to moisture transfer, conventional drying is time- and energy-consuming and quality maintenance during drying is extremely difficult due to continuous exposure to heat and atmospheric oxygen. This dehydration process results in compositional changes in flavor, color, shape and nutritional value. The only acceptable method of dehydration which maintains the quality of the dried fruits is freeze-drying. Industrial application of freeze-drying to a wide range of fruits has been limited primarily by high capital and operating costs and long drying time (Salunkhe et al., 1991; Somogyi and Luh, 1986). Since freeze-drying is very energy-intensive and time-consuming, freeze-dried products are expensive. Hence, alternate methods are

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being investigated to produce dried fruit of a quality almost equal to that of freeze-dried products. The potential economic benefits of combined microwave-convection drying have been recognized for many years (White, 1978). Microwave drying has been tried in combination with several other methods of dehydration such as convective, vacuum and freeze-drying. Yang and Atallah (1985) studied the quality of lowbush blueberries dried by four methods and reported that microwave-assisted convection drying achieved the desired moisture level within the least time. Chin et al. (1985) used a microwave oven to dehydrate tomato products to determine the total solids and compared the results with those obtained by vacuum-oven drying. Al-Duri and McIntyre (1991) used a convection oven, microwave oven and a combined microwave-convection oven for comparing the drying kinetics of milk and milk products and fresh pasta. Bouraoui et al. (1994) employed convective and combined microwave and convective drying to dry potato slices. They concluded that microwave drying has the potential for better quality dried products while reducing drying time. Drouzas and Schubert (1996) investigated the microwave vacuum drying of banana slices. The product quality was evaluated by taste, aroma, smell and rehydration tests and found to be excellent. Yongsawatdigul and Gunasekaran (1996) used the microwave-vacuum drying method to dry cranberries and concluded that the microwave-vacuum dried berries were comparable in quality with that of hot air dried berries. In this investigation, whole, sliced and pureed strawberries were dried in a convective and microwave environment. Some quality aspects of the dried product were determined and compared with those of freeze-dried strawberries.

2. MATERIALS AND METHODS

2.1 Microwave Drying Set up

A programmable microwave oven (Eaton Viking) was modified and used in the experiments on whole, sliced and pureed strawberries. A schematic diagram is presented in Fig. 1. The oven had a nominal power of 600 W and was operated at 2450 MHz. The cavity volume was 0.4 m^3. Duty cycles from 0 to 100% could be chosen in increments of 10%. However, the applied power was always 100% of the rating during "on" portions of duty cycles. The commercial unit was modified for the experimental work as follows. A 0.2 m diameter hole was drilled into the bottom of the microwave oven. An acrylic pipe of 0.2 m inside diameter was firmly attached to the hole, forming a duct for the delivery of temperature modulated air. A fine mesh metallic screen was fitted to the top of the pipe at the cavity floor level to prevent microwave leakage. A small hole was drilled through the back wall of the oven fitted with a metal wire mesh to serve as the air outlet. Air was introduced into the chamber through the tube using a 0.25 kW blower from below the oven. Heating elements (2 kW) were positioned along the air supply pipe length to heat the incoming air, the temperature being controlled using a power regulator. A mercury-in-glass thermometer fixed at the bottom of the oven was used to monitor the inlet air temperature. A second piece of the same acrylic pipe, with a perforated Teflon bottom, served as a sample holder for the fruit.

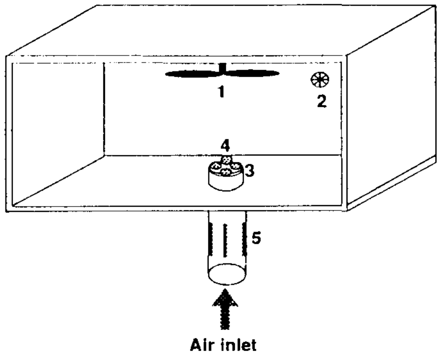

Fig. 1: Microwave drying set up (1. Mode stirrer, 2. Air outlet, 3. Sample holder, 4. Berry slices, 5. Heating elements)

During the test runs, the sample holder was placed in the microwave oven just above the hole to force the conditioned air through an evenly placed thin layer of whole or sliced strawberries. A mechanically-driven, fan-type, mode stirrer was fixed at the top of the microwave oven to promote better uniformity of microwave distribution. A hot wire anemometer was used to measure the air velocity through the inlet. The air velocity, at oven inlet, was set to 2 m/s ± 3%, since in the first set of tests higher air flow rates were found to result in fluidization of samples towards the end of the drying period. Because this set up could not accommodate real-time measurements of mass, the microwave was turned off every twenty minutes, and samples were taken out and weighed on a digital electronic balance then immediately put back in the oven.

2.2 Initial Investigations

Strawberries of unknown cultivar were procured from the market and stored in a cold room at 1°C. The fruits were removed from the cold room about 2 h before the experiments to attain room temperature. Samples were taken for the initial moisture content determination using standard oven method at low temperature. The initial moisture content of strawberries varied from 89 to 92% across all the experiments. About 100 g of the fruits were weighed and taken for microwave drying in the modified microwave drying equipment shown in Fig. 1 and explained above.

2.3 Microwave Drying of Whole Strawberries

The first trials were conducted to evaluate the possibility of drying whole strawberries in a microwave field without any preliminary treatments. These trials were performed under purely convective conditions with air heated to 35 °C, and at five microwave duty cycles of 10, 20, 30, 40 and 50% (power level (PL) 1, 2, 3, 4 and 5 respectively). It was found that at 40 and 50% duty cycles, there was burning of the product. At lower power levels (1, 2 and 3) the fruit failed to dry; rather they swelled and burst open, releasing juice (bleeding).

Since this behavior was thought to be related to high resistance to diffusion at the skin, a physical method to circumvent this problem was attempted. This involved puncturing the surface of the fruit with a pin at 15 locations. Nevertheless, the vapor pressure inside the fruit was still too high and the fruit burst open and started bleeding even at the low power levels.

Berries exposed to convective conditions at reasonably low temperatures also failed to dry. Rather, they lost their color and became very soft. Under these conditions, however, they did not burst. Since the products were so poor, no quality assessments were made. These initial experiments led to the idea of slicing and pureeing, to overcome the problem of skin resistance to moisture transport. Moreover, the fruit freeze-drying industry does market strawberry pieces and slices. Fruit leathers (dried puree strips) are also sold to hikers and campers for sustenance.

2.4 Drying of Sliced Strawberries

A knife, with three parallel blades, 1 cm apart, was fabricated and used to produce strawberry slices. In the experiments reported here, about 100 g of strawberry slices were spread evenly on a sample holder in a single layer for each drying experiment. Convective drying and microwave drying at duty cycles of 20, 30 and 40% (power levels 2, 3 and 4) were each studied at inlet air temperatures of 30, 35 and 40 °C with three replications. A duty cycle of 10% was not used because initial trials had shown that there was no advantage over convective drying. Drying continued until the weight indicated that a target moisture content of about 0.2 kg/kg (dry basis) had been reached, which is the moisture level of commercially-dried fruit samples (Bains et al., 1989).

2.5 Drying of Strawberry Puree

For the runs with the pureed strawberries, good quality strawberries were selected from the cold storage and allowed to reach ambient temperature. About 100 g of strawberries were pureed using a domestic blender at a constant speed for five minutes. Fiberglass pads of 10 x 10 cm were used to hold the puree since these allowed the air to pass through them while retaining the puree for dehydration. The same inlet air conditions were used as for the slices. The target moisture content was also 0.2 kg/kg (dry basis). However, the duty cycles here were 10, 20 and 30% since it was expected that the purees would dry much faster than the slices. As before, the reduction in mass at every 20 minute interval was recorded.

2.6 Freeze-Drying

About 2 kg of strawberries were selected from the storage and allowed to attain the ambient temperature. Half of the strawberries were cut into slices and the other half were pureed in the blender as explained above. The sliced and pureed samples were transferred into trays after obtaining their initial mass. These trays were kept in a tunnel freeze-dryer and dried for 24 hours or more until the final moisture was reached.

2.7 Quality Evaluations

The microwave-dried berry slices and puree were compared with the freeze-dried slices and puree for rehydration, color, and sensory value, using the methods described below. In these preliminary experiments, the rehydration of dried samples was performed by using the method recommended by the USDA (Anon., 1944). A 5 g sample of the dry material was boiled in distilled water for five minutes. The sample was removed, light suction was applied to remove the surface water and it was weighed. Rehydration was calculated as the ratio of mass of rehydrated sample to that of the dehydrated sample. The color of the fresh and dried samples was measured using a chromameter. The chromameter was calibrated against a standard white surface plate. The L, **a**, and **b** coordinates were measured thrice for each sample. L is the lightness variable, and **a** and **b** are the chromaticity coordinates. Color was expressed as the ratio **a/b**, which is a convenient way of reducing two color parameters to one (Francis and Clydesdale, 1975). A higher **a/b** ratio indicates change in color, a darker (more red) product. The sensory evaluation of the product was performed by a panel of five judges. Assessments were based on the presence or absence of serious visual and flavor defects (color uniformity, burnt color or flavor). The product was considered "good" when it was uniform in color with no serious defects such as stickiness, burnt color or flavor, or cracks; it was considered "poor" when it had substantial color and flavor defects. When the defects were only marginal, it was considered "satisfactory".

3. RESULTS AND DISCUSSION

The initial moisture content of the strawberry slices and puree varied from 86 to 92% (wet basis), which corresponds to an average of 8.09 kg/kg (dry basis).

3.1 Drying Slices

Table 1 shows that the influence on drying times due to inlet air temperature (30, 35 and 40 °C) was slight compared to power level. The Duncan's groupings showed that the drying times were significantly shorter for inlet air temperatures of 40 °C.

At power level 2, the average drying time across the inlet air temperatures was about 50% of that for convection. Drying times were significantly shorter at power levels 3 and 4 than at power level 2. However, the slices had burnt areas (black spots) because of concentration of microwave power, in spite of the mode stirrer having been provided in the microwave equipment. Even if the quality had been good, there would have been little value in increasing the microwave duty cycle from 30 to 40% since the time savings of one minute was not significant (Table 2). The reduction in drying time due to an increase in duty cycle decays rapidly because the drying efficiency of the applied energy decreases.

Table 1: Drying times required for slices to obtain a moisture content of 0.2 kg/kg (d.b.) at different power levels and inlet air temperatures

Power level	Drying time (minutes)		
	30 °C	35 °C	40 °C
0	120	120	100
1	120	120	90
2	60	60	55
3	45	45	40
4	40	40	40

Table 2: Mean drying time of slices at different power levels

Power	Mean (minutes)	Duncan's grouping
0	115.0*	A+
2	59.4	B
3	43.3	C
4	42.2	C

* Values are means of three replicates. + Means with the same letter are not significantly different at the 0.05 level.

This is likely due to an over-production of heat relative to the rates of moisture removal from the surface and diffusion from the interior to the surface. The dry basis moisture contents of slices were plotted against time for inlet air temperature of 35 °C (Fig. 2) for power levels 0, 2, 3 and 4.

3.2 Drying Puree

Table 3 shows the drying times for puree at the various experimental conditions. Again, the influence of inlet air temperature on drying times was significant, but much smaller than that of power level. It was the 40 °C inlet air temperature that improved the drying rate, with no significant improvement from 30 to 35 °C (Table 3).

A 10% duty cycle did not yield much improvement over convection, although the difference was significant (Table 4). The effects of 20 and 30% duty cycles were to reduce drying time by 5/6 and 9/10 of the time required for convective air drying. Again, at power level 3, the product had burnt spots. Therefore, power 4 was not attempted. The drying kinetics of puree are presented in Fig. 3. Although fiberglass pads were used as a support for the puree in the microwave oven, it was difficult to separate the dried puree from the pads. Hence, it is recommended that some other type of puree holder be used which could be more easily separated from the product. A comparison of the drying kinetics of slices and puree is given in Fig. 4 for power level 2 and an inlet air temperature of 35 °C. It is clear from the figure that puree dries faster than slices. This might be due to the thickness of the drying product. Slices were 1 cm thick, but the puree tended to spread on the pad and become thinner than 1 cm.

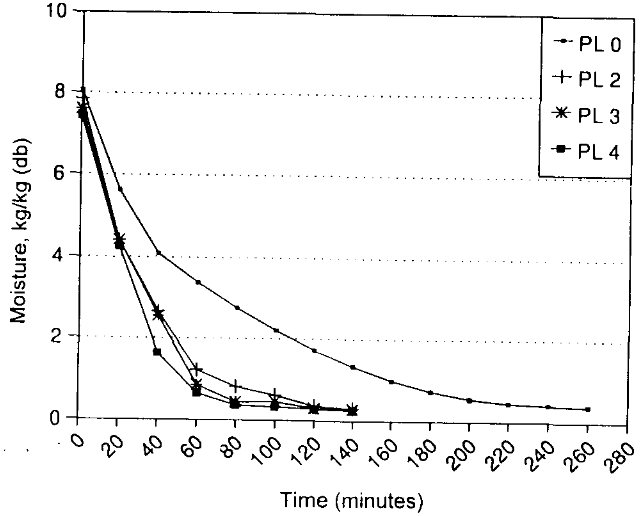

Fig. 2: Average dehydration of strawberry slices under microwave power levels 0, 2, 3 and 4 at 35 °C inlet air temperature (PL = power level)

Table 3: Drying time required for puree to obtain a moisture content of 0.2 kg/kg (d. b.) at different power levels and inlet air temperatures

Power level	Drying time (minutes)		
	30 °C	35 °C	40 °C
0	180	180	180
1	180	180	170
2	35	30	30
3	18	18	17

Table 4: Mean drying time of puree at different power levels

Power	Mean (minutes)	Duncan's groupings
0	205.6	A+
1	190.0	B
2	42.8	C
3	18.3	C

+ Means with the same letter are not significantly different at the 0.05 level

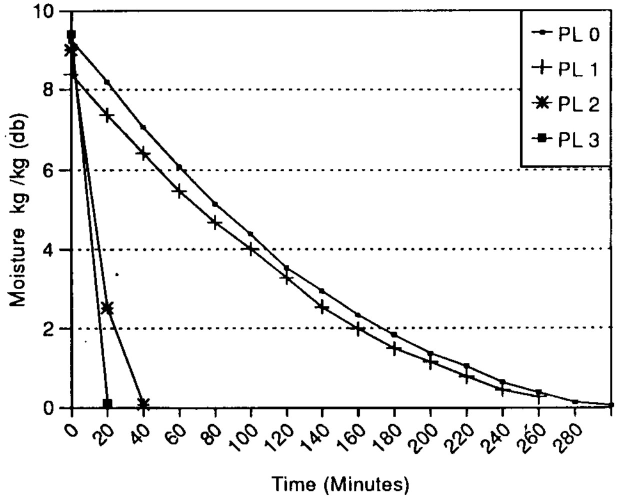

Fig. 3: Average dehydration of strawberry puree under microwave power levels 0, 1, 2 and 3 at 35 °C inlet air temperature (PL = power level)

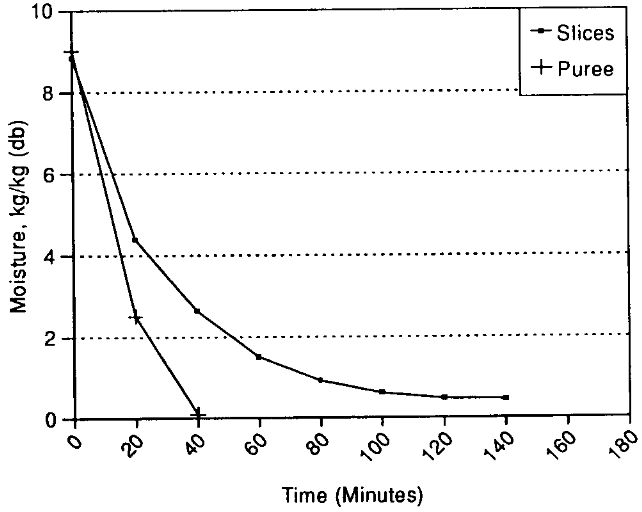

Fig. 4: Average dehydration of strawberry slices and puree under microwave power level 2 at 35 °C inlet air temperature

3.3 Quality Evaluations

Table 5 gives the rehydration (RH) ratio for microwave, convective and freeze-dried strawberry slices. Duncan's means separation test showed that there were no significant differences between rehydration ratios of the microwave-dried slices due to different power levels. However, both the convection and freeze-dried products had significantly higher rehydration ratios than microwave-dried ones, the freeze-dried product having the highest. This may be due to the freeze-dried product having a higher porosity (since it does not shrink). The rehydration characteristics of the microwave and freeze-dried purees could not be determined because the product would come apart in boiling water and could not be separated well, even by filtering.

Table 5: Rehydration (RH) ratio of microwave dried and freeze-dried strawberry slices

Treatment	RH ratio (g/g)
Convection dried	2.91 B*
Microwave dried at 10% duty cycle	2.82 B C
Microwave dried at 20% duty cycle	2.72 C
Microwave dried at 30% duty cycle	2.71 C
Freeze dried	3.80 A

* Means with the same letter are not significantly different at the 0.05 level

The results of the chromacity measurements are presented in Table 6. It is evident that the freeze-dried berries (slices and puree) were brighter red (higher **a/b** ratios) than the microwave-dried berries (slices and puree) and the fresh berries.

Table 6: Chromacity measurements (**a/b**) for microwave (MW) and freeze-dried (FD) strawberry slices and puree

Treatment	Means of (**a/b**) values	Grouping
1. Fresh (slices)	1.21	B*
2. FD (slices)	2.15	A
3. FD (puree)	2.13	A
4. MW 20%(slices)	1.08	B
5. MW 20% (puree)	1.21	B

* Means with the same letter are not significantly different at the 0.05 level

Freeze drying allows the retention or prevents the modification of compounds involved in pigmentation while at the same time concentrating them due to dehydration. This leads to dense color. Because microwave drying involves heating, transformations and volatilization losses may occur to an extent not counterbalanced by concentration. Thus, the microwaved product has about the same brightness and color as the fresh product. Chemical analyses would be needed to verify these hypotheses.

The quality judgement of the microwave and freeze-dried strawberry slices and puree from the five member judges panel is given in Table 7. These results show that the acceptability of the product goes down as the microwave power level increases (score of 5 and above is acceptable for quality), even though the drying time is lower. It may be that the higher power levels produced higher product temperatures; such temperatures may have been responsible for lowering the product quality. The microwave-dried product is clearly inferior to the freeze-dried product. The microwave-dried slices at a 20% duty cycle are about the same quality as the convection-dried product at 35 °C, but the microwave-dried puree is of lower quality. The freeze-dried product is highly acceptable.

Table 7: Means separation by Duncan's new multiple range test for the quality assessment of microwave (MW) and freeze-dried (FD) slices and puree by the judges

Treatment	Slices		Puree	
	Mean score	Grouping	Mean score	Grouping
Convection	2.86	B*	4.19	B
MW 10%	n/a	n/a	2.86	BC
MW 20%	2.60	B	2.86	BC
MW 30%	1.26	C	2.33	C
MW 40%	1.26	C	n/a	n/a
Freeze- dried	8.60	A	8.60	A

* Means with the same letter are not significantly different at the 0.05 level

4. CONCLUSIONS

Convection drying at low temperatures is very slow and leaves the berries vulnerable to spoilage. Whole strawberries, dried in a microwave field, will swell, burst and bleed. Puncturing the strawberries did not help in reducing bursting and bleeding. The drying rate was not improved by raising the inlet air temperature from 30 to 35 °C, but was significantly improved with a further increase to 40 °C. The results of these experiments indicate that, although there is a great potential time-savings in drying strawberry slices and puree with microwaves compared to either convection or freeze-drying, there is no advantage in terms of quality retention or rehydration characteristics. Furthermore, it is important to restrict the rate of excitation to less than 50% power level by microwaves to prevent burning. This restricts the time-savings possible. Freeze-dried strawberries were rated of higher quality for all the characteristics tested.

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