Pasteurization of Citrus Juice with Microwave Energy in a Continuous-Flow Unit†

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Conventional heat pasteurization of orange juice sometimes results in an off-flavor due to overheating of the juice at the heat-exchange surface. Heating with microwave energy heats the juice uniformly without changing the taste. A domestic microwave oven was modified to serve as a continuous-fluid pasteurizer by the addition of a Teflon coil and an external pump. This was used to assess the heating characteristics of citrus juice and the effects on juice quality. Complete inactivation of bacteria and pectin methylesterase was obtained. There was no adverse effect on juice flavor. A continuous-flow unit using microwave energy will be further developed for use by small-scale processors.

INTRODUCTION

Consumer interests in freshly squeezed orange juice and juice not from concentrate suggest a need to minimize the heat processing of orange juice. Freshly squeezed juice suffers short shelf life while conventional reconstituted juice from concentrate loses some flavor characteristics. Thus, pasteurized juice not from concentrate is a compromise between unpasteurized fresh juice and overprocessed evaporated concentrate. Innovative methods for improving the pasteurization of orange juice should be developed.

Orange juice and other citrus products are often pasteurized to destroy microorganisms and to reduce pectin methylesterase (PME) activity. Pasteurized juice has longer shelf life and can be adapted to aseptic packaging for the juice to be stored at chilled or ambient temperatures.

Pasteurization is commercially done at present by passing the product through a steam or hot water heat exchanger. The process is time and temperature dependent as described by Eagerman and Rouse (1976). Typical treatment conditions are 91°C for 10–60 s. Flow rates must provide turbulent conditions so that the surface layer of the juice is not overheated on the heat exchanger. Overheating leads to an off-flavor of the juice and fouling of the heat-exchange surface.

The use of microwave energy to pasteurize orange juice was investigated by Copson (1954). He reported inactivation of PME in orange juice concentrate at a 2450-MHz frequency. Erickson (1963) described the Sergeant electronic evaporator which had limited commercial use. He used a lower frequency, 30 MHz, to provide heat for evaporation rather than for pasteurization.

There are two excellent reviews of general microwave technology which briefly mention juice processing and also provide much theoretical and technical background (Decareau and Mudget, 1985; Mudget and Schwartzberg, 1982). A survey article by Giese (1992) reviews the use of microwave processing in foods. There is also a published symposia in *Food Technology* (1992) which covers microwaving many foods and briefly discusses juice processing. Pasteurization of milk with microwave energy has been studied by Hamid *et al.* (1969), Jaynes (1975), and Kudra *et al.* (1991).

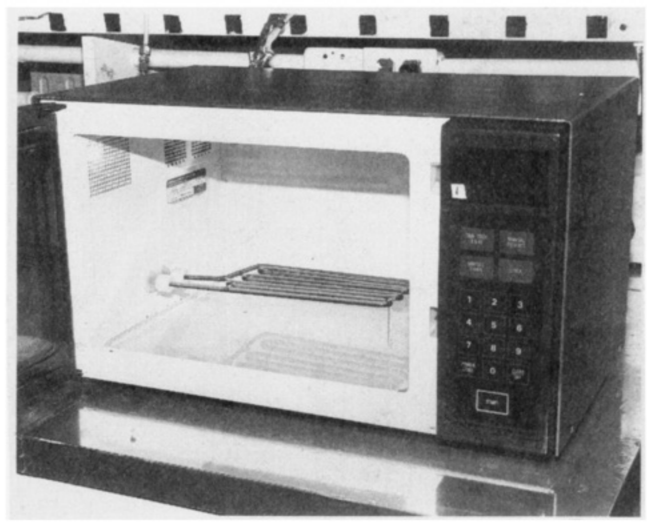

Figure 1. Microwave oven adapted to fluid processing.

The advantages for the use of microwave energy are (1) heating the juice directly, (2) no heat-transfer films, (3) improved temperature control, (4) rapid startup and cooldown, and (5) less heat lost to the environment. It is the purpose of this study to investigate microwave energy for pasteurization of citrus juice and to evaluate the benefit on juice quality.

MATERIALS AND METHODS

Continuous Microwave Processor. A 1-ft^3 domestic microwave oven, GE no. JE1019H, 600-W nominal power, 2450-MHZ frequency, was modified for the continuous-flow treatment of citrus juice (Figure 1). Two bulkhead fittings for $^1/_4$-in. tubing were installed in the lower left side of the cavity. These fittings would accept a variety of $^1/_4$-in. glass or Teflon coils. The fittings were connected outside the cavity to $^1/_4$-in. stainless steel 90° fittings to prevent microwave leakage from the cavity. These fittings were immediately followed by Teflon adapters for stainless steel thermocouples, one for entering and one for exiting fluid. The exiting fluid entered a heavily insulated, $^1/_4$-in. Teflon tube leading to a stainless steel coil immersed in a 10 °C refrigerated bath (Figure 2). The length of the insulated tube could

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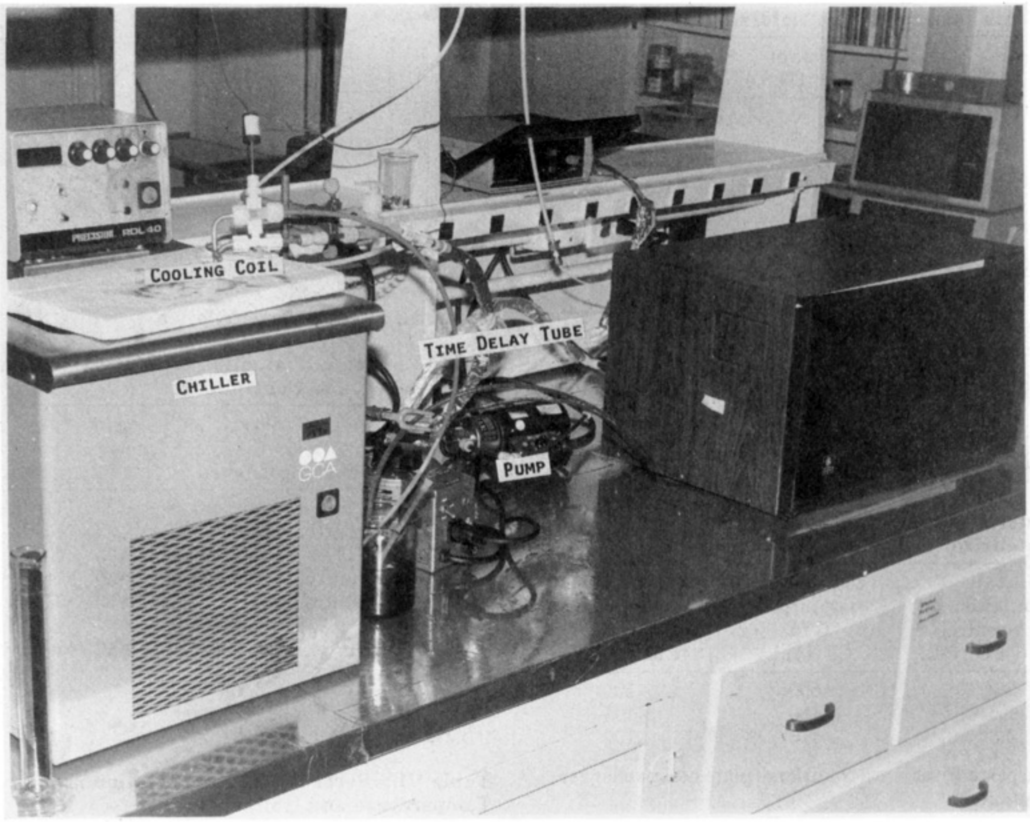

Figure 2. Microwave juice processing system.

be adjusted by inserting extra sections. Thermocouples were located at the end of the holding tube and at the exit to the cooling coil. Fluid flow was maintained at specific rates between 0 and 200 mL/min using a magnetically coupled gear pump driven by a variable speed motor, Micropump 81406.

The flow system was modified to feed from a closed reservoir with room air being allowed to enter the reservoir through a flow meter. The flow meter was calibrated by directly measuring the volumes of juice delivered over varying times.

The oven output was determined by the water-load method described by Copson (1975). In this method, 1000 g of water at 20 °C is heated for 2 min and the final temperature is measured. Power (P) is calculated as $P = 35\Delta T$. The output was 570 W using a line power of 1400 W as determined by a watt meter. This corresponds to 41% efficiency. The oven was always operated at 100% power to avoid the temperature cycles which would result from the intermittent operation of the magnetron at lower power settings.

Temperature Equilibration. Fluid temperature control was managed by adjusting the flow rate using the variable speed pump monitored by the flow meter. Initial experiments were done to determine the equilibrium temperature at various flow rates for water and fresh, single-strength orange juice. The test fluid was pumped through the microwave cavity with the unit operating at 100% power until the temperature stabilized. This required 3–5 min and allowed the system components to reach the operating temperature. These materials, mostly the Teflon tubing, do not absorb heat from the microwave energy but are heated by contact with the hot fluid. The equilibrium temperatures at several flow rates are shown in Table I. The differences between the values for water and single-strength orange juice (SSOJ) correspond to the differences in the specific heats (Chen, 1993).

Microbial Inactivation. *Lactobacillus plantarum* was incubated for 16 h at 30 °C in filter-sterilized (0.2 μm) orange serum. Cells were harvested by centrifugation (10 min at 12 000*g*) and resuspended in commercial frozen concentrated orange juice (FCOJ) reconstituted to 11.8 °Brix with sterile water.

The inoculated orange juice was microwaved to give 0-, 5-, 10-, and 15-s holdings at 70 and 80 °C. Bacteria were enumerated by spiral plating in duplicate on orange serum agar (OSA) incubated at 30 °C for 48 h. In a separate experiment, the inoculated OJ (prepared as above) was treated in the microwave system at 80, 85, and 90 °C with a 30-s residence time.

Table I. Equilibrium Temperatures of Fluids Heated at 570-W Power[a]

	equilibrium temperature (°C)	
flow rate (mL/s)	distilled water	orange juice (11.8 °Brix)
1.74	95	98.5
1.88	90	92
2.04	85	87
2.22	80	83
2.72	70	72
3.49	50	51

[a] 0.6- × 100-cm Teflon tube.

Twenty liters of commercial fresh squeezed orange juice (13.0 °Brix) was processed in the microwave at 89–91 °C for 30 s. Another 20 L was processed in a pilot plant hot water heated pasteurizer at 90.5 °C for 30 s at a rate of 2.8 L/min. Microorganisms were enumerated by spiral plating on OSA immediately after exposure and again after storage at 4 °C for 7 and 14 days (Table IV).

Pectin Methylesterase Inactivation. A 1-L sample of single-strength orange juice was treated in the microwave at several temperatures from 75 to 92 °C using 10- and 15-s residence times. Another portion of the juice was pasteurized in the pilot plant heat exchanger at 90.5 °C for 15 s.

PME activity was measured in samples by the method of Rouse and Atkins (1952). In this method, the rate of formation of free carboxyl groups is measured at 30 °C in the presence of excess pectin. Results are calculated in PME units (mequiv of COO^- per min per mL × 10^4). The reported PME reduction is calculated as (Table VI):

$$\%\ PME_i = [(PME_O - PME_F)/(PME_O)]100$$

where PME_i = PME inactivation, PME_O = PME original, and PME_F = PME final.

Table II. Bacteria Inactivation vs Holding Time

time at 70 °C (s)	CFU[a]/mL	time at 80 °C (s)	CFU[a]/mL
0	1.8×10^8	0	5.9×10^8
5	2.7×10^4	5	4.6×10^4
10	1.6×10^3	10	1.5×10^3
15	5.0×10^2	15	<10

[a] Colony forming units.

Table III. Bacteria Inactivation vs Process Temperature (Orange Juice 11.8 °Brix, 30-s Holding Time)

temperature (°C)	bacteria (CFU[a]/mL)
control, no treatment	6.2×10^7
90	<10
85	<10
80	<10

[a] Colony forming units.

Table IV. Bacteria Inactivation for a Conventional and Microwave Pasteurizer as a Function of Time

storage time at 4 °C (days)	unpasteurized control (CFU[b]/mL)	conventional pasteurizer[a] (91 °C for 30 s, CFU/mL)	microwave pasteurizer (90 °C for 30 s, CFU/mL)
1	2×10^4	550	<10
7	2.6×10^3	180	<10
14	4.3×10^2	18	<10

[a] Conventional pasteurizer was a traditional plate heat exchanger. [b] Colony forming units.

Flavor Evaluation. The triangle taste test was used to evaluate the flavor of the samples from previously discussed PME and bacteria control evaluations. A taste panel was provided with sets of three samples—two were identical, and one was different. The panelist was asked to tell which two were alike. The two materials tested were randomly assigned to the groups. A high number of correct choices would indicate a difference between the tested materials, and a low number of correct choices, below the 33% expected from "guessing", would indicate no difference in flavor between the samples.

RESULTS AND DISCUSSION

Inactivation of *L. plantarum* in juice microwaved to 70 and 80 °C at different holding times is shown in Table II. A 6-order reduction was observed in juice heated to 70 °C and held for 15 s. The microbial population was reduced from 10^8 colony forming units/mL (CFU/mL) to levels below the limits of detection in juice heated at 80 °C for 15 s. Bacteria count reductions from about 10^8 CFU/mL to levels below the limits of detection were observed when microwaved juice was held for 30 s at 80, 85, or 90 °C (Table III).

In Table IV, a traditional hot water pasteurization is compared with microwave pasteurization. These results indicate that microwave heating produced superior bacteria inactivation compared to that expected from conventional pasteurization. The microflora resulting from the traditional pasteurization in Table IV may reflect postpasteurization contamination rather than microbial survival of the pasteurization conditions as the treatment conditions would be expected to result in lower values. The reduction in microbial populations observed in the unpasteurized juice at days 7 and 14 reflects a normal decline in numbers of nonacidoduric and mesophilic organisms prior to the usual log-phase increase in fermentative, psychrotrophic yeasts and has been observed in other studies (Fellers, 1988; Parish, 1991).

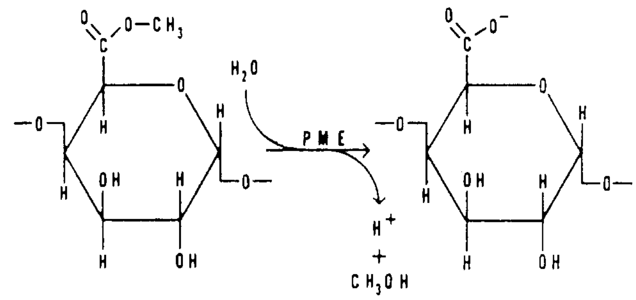

Figure 3. Pectin demethylation.

Table V. Taste Evaluation of Heat Pasteurized, Microwaved, and Control Juice

storage time at 4 °C (days)	pair compared	right choices (%)	comments
1	control vs microwave	<33	no dif
	control vs HP[a]	<33	no dif
	HP vs microwave	<33	no dif
7	control vs microwave	>50	control tasted spoiled
	control vs HP	>50	HP = microwave
	HP vs microwave	<33	no dif
14	HP vs microwave	>50	both samples tasted spoiled, HP tasted worse

[a] HP = heat pasteurized.

Table VI. Percent PME Inactivation as a Function of Temperature and Holding Time

temperature (°C)	PME inactivation (%) 10 s	15 s
75 (microwave pasteurizer)		98.5
85 (microwave pasteurizer)	99	
87 (microwave pasteurizer)	98.7	99.0
90.5 (microwave pasteurizer)		99.0
92 (microwave pasteurizer)	99.7	
97 (microwave pasteurizer)		99.5
90.5 (heat pasteurizer)		99.0

Samples reported in Table IV for PME control were tested by the triangle test for flavor differences. The results demonstrate that immediately after treatment there is no difference in flavor between the control and the two treatments, Table V. But, after storage at refrigerator temperatures for 7 and 14 days, some "spoiled" flavor developed, most notable in the control sample. No special care was taken to control the headspace atmosphere or to prevent oxygen penetration of the storage container.

Pectin is an important component of citrus juice. It contributes to the stability of the "cloud" which imparts the favorable appearance and mouth feel to orange juice. Pectin is a polygalacturonic acid shown in a simplified form in Figure 3. The material binds metal ions especially polyvalent ones. The amount and strength of the binding increases with decreasing amounts of methylation (Kertzez, 1951; Rouse and Atkins, 1952; Versteig *et al.* 1980). Citrus and other juices contain varying amounts of an enzyme, pectin methylesterase (PME), which catalyzes the hydrolysis of the methoxy groups to free carboxyl groups (Figure 3). The increasing numbers of carboxyl groups are then bound by ions present in the juice. This alters the colloid stabilizing power of the pectin and increases the rate of cloud settling. PME activity is decreased by heat treatment, and this decrease is one of the major reasons for pasteurizing citrus juice.

PME was inactivated by microwave heating between 98.5 and 99.5% at temperatures >75 °C with 10–15-s residence times (Table VI). This compared to 99.0% inactivation by traditional pasteurization for 15 s at 90.5 °C.

CONCLUSIONS

The results indicate that the continuous flow pasteurizer using microwave energy is effective for pulpy juice pasteurization. It offers a good alternative to conventional methods of pasteurization using steam-based heat exchangers. The use of microwave energy allows the pasteurization by small-scale juice processors and eliminates the need for a steam generator which is necessary for conventional methods of juice pasteurization. A state of the art unit will be developed to further the study on minimally processed citrus juice processing.

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