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Pasteurization of pickled asparagus using 915 MHz microwaves

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Abstract

Asparagus spears are sensitive to thermal treatments. Lengthy pasteurization at elevated temperatures may cause severe thermal degradation. In this research we explored the application of short-time microwave pasteurization for pickled asparagus in glass bottles and studied the effect of this process on the textural quality of the products in comparison with the conventional hot-water pasteurization method. A pilot-scale 915 MHz microwave system was used in this study for heating pickled asparagus in 1.8 kg (64 oz) glass bottles to 88°C. Heating uniformity was determined using fiber optical temperature sensors. The textural quality of asparagus was evaluated in shear tests and the *C*-value was used to assess the impact of different processes. Pasteurization of pickled asparagus using 915 MHz microwaves resulted in a uniform heating and it reduced process time by at least one-half compared to water-bath heating. Microwave pasteurization markedly reduced thermal degradation of asparagus. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Microwave; Pasteurization; Asparagus; Kinetics; Texture

1. Introduction

Pickled asparagus is gaining popularity due to its unique texture and flavor. FDA regulations (Anonymous, 1998) require that pickled products be pasteurized to inactivate vegetative cells of pathogenic and spoilage microorganisms. FDA regulations, however, do not specify a specific pasteurization procedure for pickled products. The pickle industry usually uses a procedure established in the early 1940s that recommended an internal pasteurizing temperature of 74°C for 15 min followed by prompt cooling (Fleming, 1998; Monroe et al., 1969). Some companies, however, developed their own processes for specific products.

Asparagus is a heat sensitive vegetables and its texture is usually degraded to a large extent during thermal treatments (McGlynn, Davis, & Honarmand, 1993). The activation energy for textural loss in asparagus spears at the temperatures suitable for pasteurization is between 75 and 105 kJ/mol (Lau, Tang, & Swanson, 2000; Rodrigo, Rodrigo, Fiszman, & Sanchez, 1997). Thermal destruction of bacterial vegetative cells is much more temperature dependent, with an activation energy of 420–500 kJ/mol (Lund, 1977), than for textural changes. It may, therefore, be possible to use a rapid heating process at a temperature higher than 74°C to pasteurize asparagus spears and to reduce textural degradation.

Pickled asparagus spears are commonly packaged and pasteurized in clear glass bottles. It is difficult to achieve rapid heating in the glass bottles using conventional thermal treatments that use hot-water or steam. There is an interest in developing a non-conventional heating method to pasteurize pickled asparagus to minimize quality losses.

Microwave processes can directly interact with foods in glass bottles to generate heat and may, therefore, provide more rapid heating for asparagus in bottles. Microwave pasteurization has been applied to several food products, including fresh pasta, bread, granola and prepared meals (Giese, 1992). Possible uneven heating, however, can be a major obstacle to the application of microwave heating in commercial pasteurization and sterilization in the food industry (Brody, 1992).

In the United States, two frequencies (915 and 2450 MHz) are designated by the Federal Communications Commission for industrial microwave heating applications. Most of the reported work on microwave pasteurization used 2450 MHz microwaves (Decareau, 1992; Giese, 1992; Schlegel, 1992). But in general, 915 MHz microwaves have deeper penetration depth in foods than 2450 MHz microwaves, and may, therefore,

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Nomenclature

A	area (m^2)
Bi	Biot number (dimensionless)
C-value	Cook value (min)
C_p	specific heat (kJ/kg K)
D	diameter (m)
E_a	activation energy (kJ/mol)
F	shear force (N)
L	thickness of glass bottle (m)
P	shear stress (Pa)
R	universal gas constant (8.314 kJ/mol °K)
T	temperature (°C)
V	volume (m^3)
h	heat transfer coefficient (W/m^2 K)
k	thermal conductivity (W/m K), or rate constant (min^{-1})
t	time (min)
x	radius of the sample ($r/2$ for long cylinder)
z	z-value (33°C)
ρ	density (kg/m^3)

Subscripts

w	water
i	initial condition

provide more uniform heating (Brody, 1992; Mudgett, 1989; Tong, Lentz, & Possen, 1994).

The objective of this study was to investigate the effect of 915 MHz microwave pasteurization on the heating uniformity and textural quality of pickled asparagus in 1.8 kg (64 oz) glass bottles in comparison with the conventional hot-water pasteurization method.

2. Materials and methods

2.1. Sample preparation

Fresh asparagus (*Asparagus officinalis* L. var. Mary Washington) was purchased from a local grocery store. The spears were washed with tap water and drained. Spears were then cut into 10.2 cm (4 inch) sections (measured from the bud), tightly packed in 1.8 kg (64 oz) bottles (diameter = 14 cm, height = 16.2 cm), filled with 80°C brine (1% salt and 7% vinegar) and capped with metal lids for further processing. The formula of the brine solution was obtained from a local pickle company. The pH of the brine was 3.7.

2.2. 915 MHz microwave system

A 915 MHz pilot-scale system was used in the microwave pasteurization tests (Fig. 1). This system consisted of a 5 kW power generator and a multimode stainless steel microwave cavity (1.07 m × 1.22 m × 1.47 m) (MICRODRY Model IV-5 Industrial Microwave Generator, Microdry Incorporated, Crestwood, KY). The power unit transformed a 480 V power supply to the 7500 V required by the magnetron. The magnetron converted electric energy into microwaves that were directed to the cavity via a circulator and rectangular wave-guides. The generator provided microwave power from 0.2 to 5 kW. Stability and control of the power output was maintained by the feedback of a 4–20 mA control signal from the magnetron anode current. Power meters and other control instrumentation monitored microwave power input to and reflected power from the cavity. The reflected waves from the cavity were directed to a matched water load by the circulator, thus preventing it from damaging the magnetron. Uniformity of the microwaves in the cavity was enhanced by a stirrer (0.87 m diameter, 15 rpm).

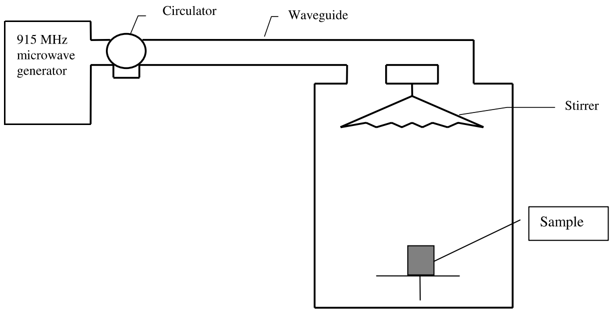

Fig. 1. Schematic diagram of 915 MHz pilot-scale microwave system (0–5 kW).

2.3. Determination of the coldest spot in microwave heating

Fiber optical temperature sensors (Photonetics, Wakefield, MA) were inserted at eight different positions in a 1.8 kg (64 oz) bottle tightly packed with pickled asparagus to obtained a complete temperature profile during microwave heating and to locate the coldest spot in the bottle during microwave heating. The temperature readings obtain from the fiber optical sensors were recorded using a data logger linked to a personal computer. Preliminary study indicated that when asparagus spears were packed in the glass bottle, the temperature differences between spears and the adjacent brine were not significant during microwave heating. Even without using microwave heating this temperature difference would be small. Harrison (1993) reported that the center temperature of asparagus spears reached the water temperature in less than 25 s when asparagus spears were individually place in a 90°C water-bath. Because of the small temperature difference between the brine and asparagus spears, all the temperature probes were inserted in the brine to reduce possible damage to the fragile fiber optical probes. Once the coldest spot was located from the temperature distribution measurements, a fiber optical sensor was placed at the slowest heating position for process control.

2.4. Water-bath heating

According to the National Canners Association Research Laboratories (1968), the coldest spot for products in glass bottle during conventional heating is located in the central axis at 1/3 of the total height or about 5.1 cm (2 in.) above the bottom of the 1.8 kg (64 oz) bottle. Therefore, when using a water-bath as a heating medium, type T (copper–constantan) thermocouples were placed at 5.1 cm (2 in.) from the bottom across the radii (center, middle and surface). Each thermocouple was interfaced with a personal computer via LabView® analog and digital board and through the LabView® Base Package for data acquisition (National Instruments, Austin, TX).

2.5. Pasteurization treatments

Asparagus (~1.2 kg of fresh asparagus) in glass containers was treated with three different pasteurization processes. The heating time and temperature for the pasteurization treatments either using microwave or water-bath heating were based on the temperature reading from the temperature probe placed at the slowest heating spot in the glass bottle. Each pasteurization process was done in duplicate.

2.5.1. Microwave heating (treatments I and II)

For treatment I, bottles with tightly packed asparagus spears were filled with 80°C brine to reach 50°C. These bottles were then heated to 70°C in a water-bath set at 80°C. Each bottle was further heated to 88°C in the 915 MHz microwave system set at 2 kW, held for 10 s. This final temperature of 88°C was chosen based on the pasteurization practices used by several local companies for pickled asparagus.

The bottles were then removed from the microwave cavity and tempered with lukewarm water at 40°C to prevent possible cracking of the glass bottles before being hydro-cooled in cold tap water (10°C) until the center temperature of the bottle reached 20°C. Treatment II was similar to treatment I, except that the microwave power level was set at 1 kW.

In a preliminary study using 915 MHz microwaves, we observed over-heating in the top portion of the glass bottles. We believed that the microwaves passing through the glass wall (curved bottle neck) over the head space of the glass bottle focused on the top portion of the brine, causing localized over-heating. Covering the top one-third of the bottle with aluminum foil eliminated the over-heating. This shielding method was used in the pasteurization experiments to ensure heating uniformity.

2.5.2. Conventional heating (treatment III)

Pickled asparagus in 1.8 kg (64 oz) bottles were hot-filled with brine at 80°C to reach an equilibrium temperature of 50°C. The bottles were heated in a water-bath set at the water boiling temperature. Once the brine temperature at the coldest spot reached 88°C (Fig. 2), the temperature was held for 10 s. The bottles were removed from the water-bath, first tempered with lukewarm water (40°C) for 30 s followed by further cooling with running tap water (10°C) to stop further heating of the product.

2.5.3. Temperature gradient in asparagus bottles

Biot number (*Bi*) was used to help to gain an insight into the heating uniformity in the bottle filled with pickled asparagus. If $Bi \leqslant 0.1$, it is reasonable to assume a uniform temperature distribution in a solid at any time during a transient process. If $Bi \geqslant 0.1$, there is a non-uniform heating within the sample. *Bi* is defined as (Incropera & DeWitt, 1981):

$$Bi = \frac{hx}{k}, \tag{1}$$

where h is the convection coefficient between the brine in a glass bottle and the heating medium, k is the thermal conductivity of the brine and sample (~0.6 W/m K) in the glass bottles, and x is the radius of the bottles ($r/2$ for a long cylinder, where r is the radius of the cylinder). In this study, a lumped convection coefficient h was used:

$$\frac{1}{h} = \frac{1}{h_1} + \frac{L}{k_g}, \tag{2}$$

where h is the overall convection coefficient, h_1 is the heat transfer coefficient between the boiling water (500 W/m^2 K) and the bottle surface, L is the thickness of glass bottle (2×10^{-3} m) and k_g is the thermal conductivity of glass (0.52 W/m K).

2.6. Measurement of texture

The textural quality of pickled asparagus after different pasteurization treatments was evaluated using shear tests. Ten asparagus spears were randomly taken from pasteurized bottles for each treatment. Each spear was cut into three segments (bud, middle, and butts) with a sharp knife. The texture of each segment was evaluated using a single blade and a test cell (Fig. 2) on a TA.XT2 Texture Analyzer (Texture Technologies, Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK). The cross-head speed was set at 3.0 mm/s. In this study, the maximum shear stress required to cut through a sample was used to represent the pickled

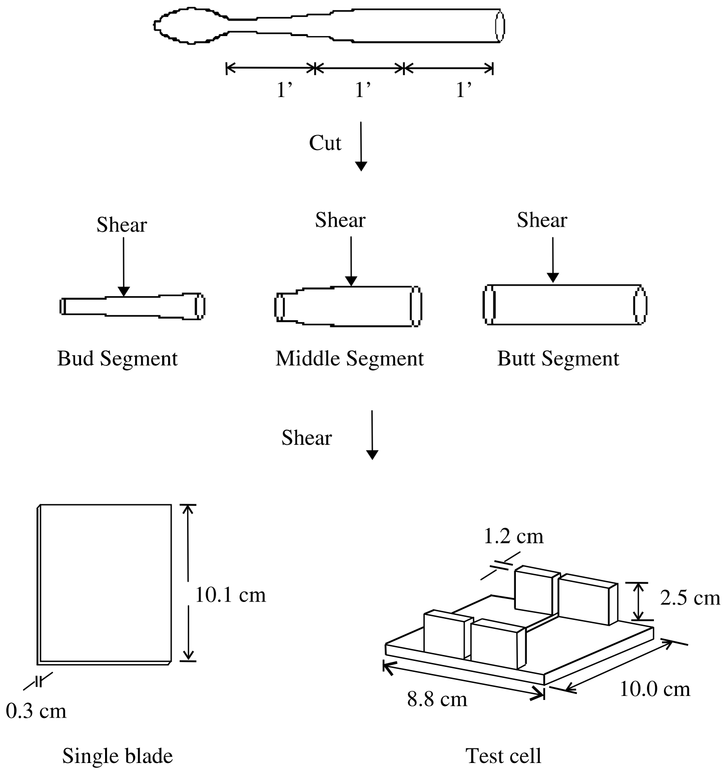

Fig. 2. Shear measurements for pickled asparagus using single blade and test cell for TA.XT2 Texture Analyzer.

asparagus texture. The maximum shear stresses experienced on each side of the blade were determined using the following equation:

$$P = \frac{F}{2 \times (\pi D^2/4)}, \tag{3}$$

where P is the maximum shear stress (Pa), F is the measured maximum force (N) that cut through the specimen and D is the diameter (m) of the test segment of an asparagus spear.

2.7. Peroxidase testing

A major concern over short-time pasteurization processes is the possibility that enzymes causing quality changes during storage are not inactivated. In order to check the adequacy of our treatments in inactivating enzymes in asparagus, peroxidase activity was determined using a substrate solution that contained 5 mM of hydrogen peroxide and 5 mM guaiacol in 200 mM acetate buffer at pH 5.6 (Adams, 1997). After each heat treatment, 10 asparagus spears were randomly selected from each bottle for the peroxidase testing. The selected spears were first divided into three sections. Each section (2 cm in length) was blended with the enzyme substrate solution 3 ml at ambient temperature (25°C). A positive testing for the presence of peroxidase was indicated by a formation of brown color on the cut surface of green asparagus. Proper inactivation of peroxidase (negative testing) by heat treatment was indicated by no change of color in the blended green asparagus with the substrate solution after 3 min of testing.

2.8. Cook value

Cook value (C-value) was used to evaluate the thermal effect of different processes on the quality of pickled asparagus. Mansfield (1975) introduced the concept of C-value for evaluation of sensory degradation. The C-value has a reference temperature of 100°C and z-value of 33°C. The z-value of 33°C was based on the average of the deterioration of chemical components such as thiamin, vitamin C and chlorophyll (Ohlsson, 1980). The C-value was estimated from:

$$C = \int 10^{[T(t)-T_{\mathrm{ref}}]/z}\,\mathrm{d}t, \tag{4}$$

where C is the Cook value at $T_{\mathrm{ref}} = 100°\mathrm{C}$, T is the product temperature and it was a function of time, and t is the time. The C-value for each process was calculated by numerical integration of Eq. (4) using time–temperature data obtained from treatments I, II and III at the fastest heated location in the glass bottle.

2.9. Prediction of maximum shear stresses of pickled asparagus

Textural degradation of pickled asparagus due to pasteurization was predicted using the kinetic parameters obtained in a separate study (Lau et al., 2000). The activation energies (E_a) and rate constants for different asparagus segments at a reference temperature ($k_{84^\circ\mathrm{C}}$) are listed in Table 1. In the kinetics studies, asparagus spears were heated in distilled water. The rate of change in the maximum shear stresses to cut through asparagus samples can be modeled using a differential equation:

$$\frac{\mathrm{d}P}{\mathrm{d}t} = -kP, \tag{5}$$

where P is the shear stress of asparagus, t is the time, k is rate constant.The rate constant k is related to temperature by an Arrhenius relationship (Lau et al., 2000)

$$k = k_A \exp\left[-\frac{E_a}{R}\left(\frac{1}{T}-\frac{1}{T_a}\right)\right], \tag{6}$$

where $k_A = k_{84^\circ\mathrm{C}}$ (Table 1), E_a is the activation energy (Table 1), R is the universal gas constant, T_a is the reference temperature (357.16 K) and T is the process temperature in K. Substituting Eq. (6) into Eq. (5) yields:

$$\frac{\mathrm{d}P}{\mathrm{d}t} = -k_A \exp\left[-\frac{E_a}{R}\left(\frac{1}{T}-\frac{1}{T_a}\right)\right]P. \tag{7}$$

Integrating Eq. (7) gives:

$$\int_{P_0}^{P(t)} \frac{\mathrm{d}P}{P} = \int_0^t -k_A \exp\left[-\frac{E_a}{R}\left(\frac{1}{T}-\frac{1}{T_a}\right)\right]\mathrm{d}t \tag{8}$$

or

$$\ln P(t) - \ln P_0 = \int_0^t -k_A \exp\left[-\frac{E_a}{R}\left(\frac{1}{T}-\frac{1}{T_a}\right)\right]\mathrm{d}t. \tag{9}$$

Thus,

$$P(t) = P_0 \ * \exp\left(\int_0^t - k_A \exp\left[-\frac{E_a}{R}\left(\frac{1}{T}-\frac{1}{T_a}\right)\right]\mathrm{d}t\right), \tag{10}$$

where P_0 is the initial shear stress (untreated sample). The predicted shear stresses of asparagus after thermal treatments were calculated by numerical integration of Eq. (10) using temperature–time data [$T(t)$, in K] obtained from treatment I, II and III at different locations in the 1.8 kg (64 oz) bottle. The time interval for predicted shear stress calculation was 10 s. The predicted shear stress values presented in this study were the average of all the shear stress values calculated from temperature–time data obtained from different locations in the bottle.

Table 1
Kinetic data for texture degradation of green asparagus due to heating in distilled water at temperatures between 70°C and 98°C (Lau et al., 2000)

Location	E_a (kJ/mol)	$k_{84^\circ\mathrm{C}}$ (min^{-1})
Butt	104.2	0.0153
Middle	103.8	0.0224
Bud	99.2	0.0278

3. Results and discussion

3.1. Temperature–time profiles

Typical temperature–time profiles during pasteurization of bottled asparagus in boiling water and 915 MHz microwave heating (1 and 2 kW) are shown in Figs. 3–5, respectively. The time required for the bottle center temperature to reach 88°C was 30 min for conventional hot-water heating, 15 min for microwave heating using 1 kW microwave power, and 9 min for microwave

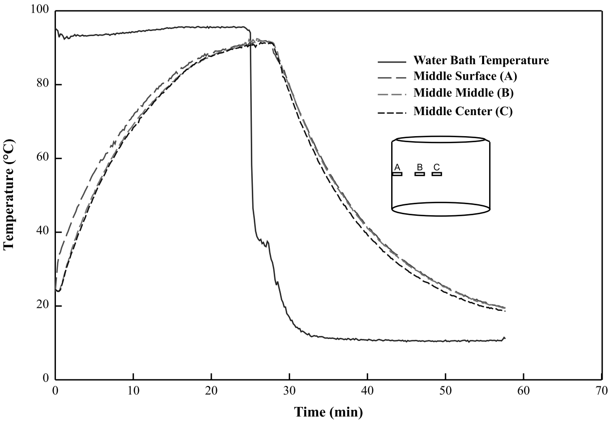

Fig. 3. Temperature–time profile of pickled asparagus using conventional heating method.

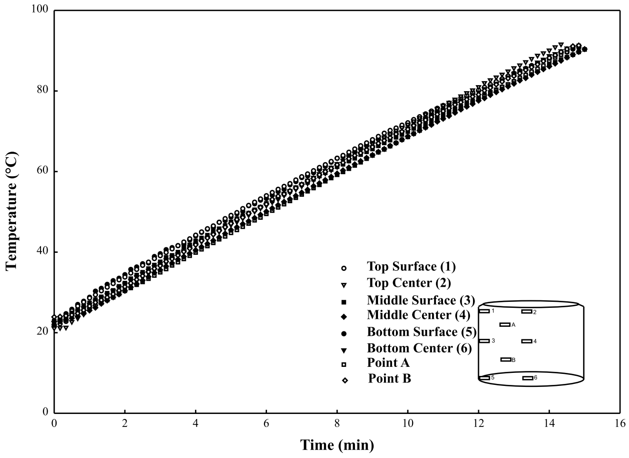

Fig. 4. Temperature–time profile of pickled asparagus using 915 MHz microwave heating at 1 kW power.

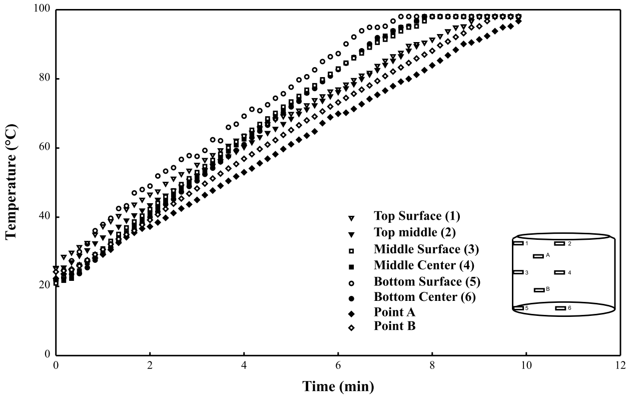

Fig. 5. Temperature–time profile of pickled asparagus using 915 MHz microwave heating at 2 kW power.

heating using 2 kW microwave power. Based on the heating curves, microwave pasteurization reached the required temperature in less than half the time necessary for the conventional heating method.

3.2. Temperature gradient during conventional heating

The calculated *Bi* for conventional hot-water heating was 9.2, much greater than 0.1. If conduction were the dominant heat transfer in the bottle, we would expect a very non-uniform temperature distribution within the glass bottles during water-bath heating at $Bi = 9.2$. Our temperature measurements indicated, in the early part of the heating, the center temperature lagged behind the temperature close to the bottle wall (Fig. 5). However, in the later part of the heating, the center temperature did not lag very much behind the brine temperature closest to the bottle wall (Fig. 3). This suggests a strong natural convection occurring in the bottles, which reduced the non-uniform heating.

The temperature–time relationship in glass bottles resembled the temperature curves predicted by the lumped capacitance model (Incropera & DeWitt, 1981):

$$\frac{T - T_\mathrm{w}}{T_\mathrm{i} - T_\mathrm{w}} = \exp\left[-\frac{h}{\rho C}\left(\frac{A}{V}\right)t\right], \tag{11}$$

where T_w is water-bath temperature, T_i is initial temperature, h is connective heat transfer coefficient, ρ is density, C is specific heat, and A/V is the surface to volume ratio, and t is time. Based on Eq. (11), the surface heat transfer coefficient and the surface area to volume ratio determine the heating rates in bottled asparagus when using the hot-water pasteurization method.

3.3. Temperature distribution during microwave heating

Brine temperature increased linearly with time during microwave heating at 1 and 2 kW (Figs. 4 and 5). Shielding of microwaves using aluminum foil prevented the over-heating on the top portion of the bottled asparagus. The temperature at the bottom surface was, however, higher than at other locations in the glass bottle, especially at 2 kW microwave power level (Fig. 5). Microwave heating was more uniform when using 1 kW microwave power than with 2 kW microwave power. At 1 kW, convective movement of the brine in the bottles might have contributed to a more uniform heating. An advantage of microwave heating over the conventional heating method appears to be the fast heating rate that can be controlled by selecting a proper microwave power. But our results suggest that compromise needs to be made between the heating rate and heating uniformity during microwave heating.

3.4. C-value

The *C*-values for pickled asparagus after different pasteurization processes are listed in Table 2. Conventional hot-water pasteurization resulted in a much higher *C*-value than the two microwave heating treatments. For conventional heating, lower *C*-value can only be obtained when a small size container is used (Ohlsson, 1980). In all cases, samples treated with the conventional method suffered much more severe thermal degradation than the two microwave treatments. This was further confirmed by the results of the textural measurements.

3.5. Textural quality

The maximum shear stresses for pickled asparagus after conventional and microwave heating treatments are shown in Figs. 6–8. In general, the maximum shear stresses for cutting through the pickled asparagus in the bud, middle and butt segments pasteurized with microwave heating were higher than those heated by the conventional hot-water method. For the microwave treatments, the maximum shear stresses for pickled asparagus pasteurized with 2 kW microwaves were higher than those pasteurized with 1 kW microwave heating, which further indicates that a rapid heating process

Table 2
C-values for pickled asparagus resulting from different pasteurization processes

Pasteurization process	Location in bottle	*C*-value (min)
Hot-filled, boiling water-bath	Surface	8.66
Hot-filled, water-bath, 1 kW microwave	Top surface	3.16
Hot-filled, water-bath, 2 kW microwave	Bottom surface	2.64

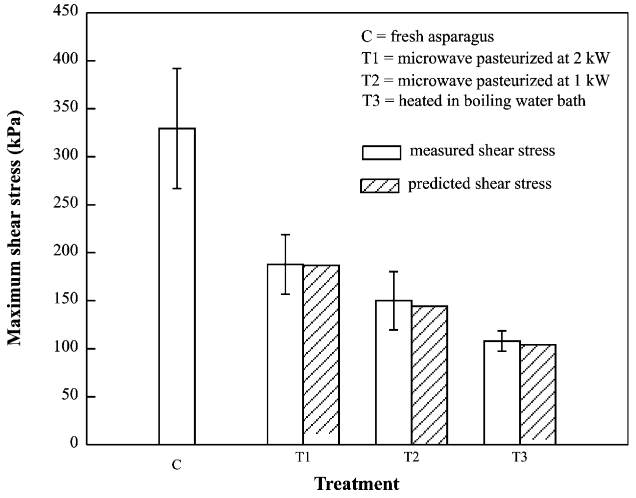

Fig. 6. Maximum shear stress for pickled asparagus (bud segment) after different heat treatments.

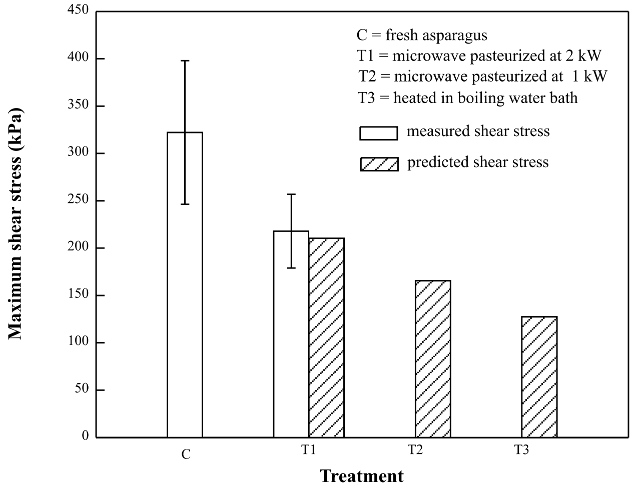

Fig. 7. Maximum shear stress for pickled asparagus (middle segment) after different heat treatments.

indeed reduced the textural degradation of pickled asparagus.

3.6. Peroxidase activities of thermal-treated green asparagus

Peroxidase activities of pasteurized green pickled asparagus are shown in Table 3. The peroxidase tests were all negative for the thermal treatments using the combination of hot-filled, water-bath and 2 kW microwave heating. For the latter treatments, only 70% of peroxidase tests were negative. The non-uniformity and/or short-time microwave heating at 2 kW might have been contributed to the residual peroxidase activities. Thus, even though the 2 kW process may reduce textural degradation due to thermal damage, the residual enzyme activity may cause quality losses during storage.

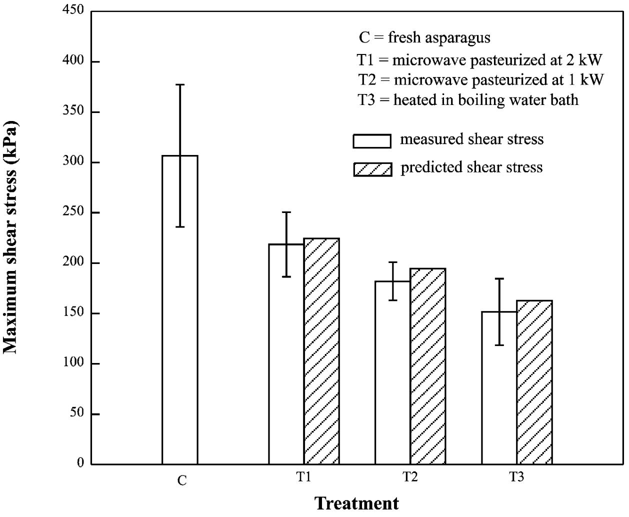

Fig. 8. Maximum shear stress of pickled asparagus (butt segment) after different heat treatments.

Table 3
Peroxidase activities of green asparagus from different pasteurization processes

Pasteurization process	Peroxidase activity
Hot-filled, boiling water-bath	All negative
Hot-filled, water-bath, 1 kW microwave	All negative
Hot-filled, water-bath, 2 kW microwave	70% negative

3.7. Validation of kinetic model

Predicted and experimental maximum shear stress values of pickled asparagus are shown in Figs. 6–8. The predicted maximum shear stresses to cut through the samples were within the range of the experimental values. The kinetic model developed in Lau et al. (2000) can, therefore, be applied to predict textural changes of asparagus due to pasteurization. In Lau et al.'s study, fresh asparagus spears were directly heated in distilled water to obtain the kinetic data for textural thermal degradation. The fact that those kinetic data applied well to the asparagus spears heated in acidified brine suggests that the brine might not have an effect on the textural changes of asparagus spears.

Our results demonstrated the advantages of rapid microwave pasteurization processes in reducing textural losses in pickled asparagus. The results, however, need to be treated with care, because they were obtained in experiments in which the bottles were treated one-at-a-time in the microwave cavity. It might not be possible to extend these results directly to industrial applications without careful engineering design of a continuous microwave cavity for treating a large number of bottles at the same time. In addition, the high pasteurization temperature of 88°C may only be applied to specific products. For example, Monroe et al. (1969) reported severe bloater damage in pickled cucumbers when pasteurized at temperatures between 77°C and 93°C.

4. Conclusions

Uniform microwave heating of bottled asparagus can be achieved by proper selection of microwave power at 915 MHz and by using partial microwave shielding of the top 1/3 of the glass bottles. Pasteurization of pickled asparagus in 1.8 kg (64 oz) glass bottles using 915 MHz microwaves can reduce the heating period by half compared with the time required for the conventional hot-water pasteurization process. Microwave pasteurization can also sharply reduce the Cook value for pickled asparagus and reduce textural degradation. Textural losses in both microwave and hot-water pasteurized pickled asparagus spears can be predicted based on the kinetic information previously obtained with fresh asparagus that were thermally processed in neutral pH solutions.

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