VARIABLE RETORT TEMPERATURE PROFILES FOR CANNED PAPAYA PUREE

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ABSTRACT

Constant retort temperature (CRT) processes for thermally treated foods are usually time-consuming and have drastic impact on food quality. Variable retort temperature (VRT) processes may decrease the processing time and may retain better the food nutritional quality. Five isolethal profiles (one CRT and four VRT) for preparing papaya puree (pH 3.8) were designed using pectin methyl esterase as the target enzyme for thermal processing, and their effect on the puree quality was evaluated. The objective was to compare these profiles based on processing time, vitamin C retention, consistency index and color. The VRT isolethal profiles reduced the processing time up to 33.3% compared with CRT, whereas vitamin C, consistency index and chroma were retained up to 65, 71 and 89%, respectively, compared with fresh puree. The best resulting treatment was a VRT upstairs profile (75C/19 min, 80C/8.5 min, 90C/10.7 min and 6C/20.8 min). The results show that the use of VRT profiles allows retaining the nutritional quality of canned papaya puree.

PRACTICAL APPLICATIONS

This research explored the use of variable retort temperature to increase product quality and improve processing time in canning of papaya puree. In an upstairs profile, 65% of vitamin C was retained compared with fresh product. The results would be useful for canning of conduction-heated foods.

INTRODUCTION

Papaya (Carica papaya L.) is an excellent source of vitamin C, carotene, fiber, minerals (e.g., magnesium, iron, copper, manganese and potassium) and several amino acids (De Oliveira and Vitória 2011). This fruit is highly perishable and its processing by suitable preservation methods is important (Fernandes et al. 2006). Papaya pulp is thermally processed as puree by pasteurization and sterilization; processed puree is stored and used in the production of soft and fermented beverages, ice cream, yoghurt jam, jelly and baked goods, among other food products. In particular, the use of papaya puree in baked food products has decreased their trans- and total-fatty acid caloric content and increased their overall nutritional value (Templeton et al. 2003; Wiese and Duffrin 2003).

In canning, a constant retort temperature (CRT) is usually employed to obtain a commercially sterile food product with an extended shelf life, but its physicochemical and sensorial characteristics are often compromised. Alternatively, the nutritional and sensory quality of the food product can be improved using high temperature and short time technologies (Simpson et al. 2003). However, the application of these treatments is not suitable in solid and highly viscous foods because conduction is the prevailing heating mechanism, requiring longer processing times to reach a proper lethality (Rahman 2007), which causes a decrease in the nutritional and sensorial quality of the food (Almonacid et al. 2012). The CRT processes of fruit purees (e.g., papaya, mango, guava, tomatoes and peas) use retort temperatures ranging from 75 to 95C (Magalhães et al. 1999); the use of 80C has been suggested as appropriate for acid or acidified fruits (Barret et al. 2005).

In the design and implementation of a thermal process, aside from the destruction of microorganisms and enzymatic inactivation, other factors that should be considered...
include the heat transfer mechanism, chemical and physical nature of the product, color and nutrient degradation kinetics, container dimensions and process-related factors (e.g., retort temperature, come up and rotational speed). An adequate lethal process should destroy deteriorative agents and also preserve the nutritional value of the food, and the best temperature–time combination to reach the required lethality must be designed.

Implementation of a variable retort temperature (VRT) process represents an alternative to conventional canning; VRT processes have been a successful strategy for conduction-heated foods (Erdogdu and Balaban 2003; Simpson et al. 2008; Abakarov and Núñez 2013). Benefits of VRT processes may include a better retention of the nutritional and sensory quality of the food, and a reduction in processing time (Chen and Ramaswamy 2004; Abakarov et al. 2009); however, previous studies have been based mainly on simulation and optimization of the temperature of retort profiles (103–140°C), frequently using quality kinetic parameters obtained from the literature. As an example, Durance et al. (1997) validated the simulated VRT process for canned salmon and estimated, from kinetic equations, the surface quality and thermal kinetics of thiamine loss. Most of the VRT studies have not been applied experimentally to actual retort operations to evaluate their impact on food quality parameters (e.g., vitamin C content, viscosity and color) or to determine their potential use for processing acid or acidified fruits, which do not require temperatures above 100°C. Remarkably, industry implementation of VRT processes could increase the plant production capacity, depending on the product and process conditions. Moreover, VRT process has not been applied in the manufacturing of acidified vegetable materials, suggesting that more information is required to evidence its benefits and industrial feasibility. The objective of this work was to assess the effect of four VRT profiles on processing time, vitamin C retention, consistency index and color of canned papaya puree compared with those processed at a CRT. All profiles were designed to achieve the same lethal effect on the activity of pectin methyl esterase.

**MATERIALS AND METHODS**

Papaya (Carica papaya L.) cv. Maradol was used at commercial ripeness (completely yellow rind). Fruits with weights ranging from 1.5 to 3 kg were obtained from a local market and kept under refrigeration (12 ± 1°C; 95% relative humidity) for less than 1 day before preparing the papaya puree.

**Preparation of Papaya Puree**

Selected fruits were free from spots and bruises, and were washed with chlorinated water (10 mg/L) to eliminate impurities. The peeling was performed with a knife; pulp was cut in pieces of about 35 × 30 × 10 mm, sieved through a 16-mm mesh and homogenized in a blender (Osterizer Classic Plus model 4127, Sunbeam Mexicana, Tlanepantla, Mexico, Mexico) at an average speed of 20 Hz (1,200 rpm). Before thermal processing, the puree was acidified to pH 3.8 with citric acid (0.5% w/w). Samples of papaya puree were taken for physicochemical characterization before processing.

**Thermal Processes Applied to Canned Papaya Puree**

The headspace for 211 × 300 cans was 6 mm, and for validating the location of the coldest spot in the food (point of lowest lethality), needle T-type thermocouples were inserted at different heights (h): geometric center (1/2 h), intermediate zone (1/3 h) and near the bottom of the can (1/4 h).

Papaya puree was heated at 60°C (filling temperature). Needle-type thermocouples were connected to a digital potentiometer (Digi-Sense; Cole-Parmer, Vernon Hills, IL) using locking connectors (model C-10; Ecklund Harrison, Fort Myers, FL) and cans were quickly subjected to the desired thermal process. The temperature histories of the food at different thermocouple locations were obtained at a CRT of 97°C, followed by a cooling period at 25°C in chlorinated water (10 mg/L). Three heat penetration tests were conducted using eight cans per test.

Once the location of the puree’s coldest spot was determined, a needle T-type thermocouple was inserted at the corresponding spot for 211 × 300 cans. For designing the profiles of papaya puree (pH 3.8), the pectin methyl esterase (PME, EC 3.1.1.11) was used as the target enzyme, using the thermal resistance values (D90°C = 7.2 min, z = 7.8°C) reported for papaya puree at pH = 3.8 (Magalhães et al. 1996). At a constant lethal temperature, the heating time for enzyme inactivation is

\[
t = D \log \frac{a_0}{a} \tag{1}
\]

where \(D\) is the decimal reduction time, \(a_0\) is the initial activity and \(a\) is the final activity. The inactivation percentage is

\[
I (%) = \frac{a_0 - a}{a_0} \times 100 \tag{2}
\]

All thermal processes applied to the puree were subjected to a 2.5D isothermal effect. Therefore, when \(t = 2.5D\) in Eq. (1), from Eq. (2), the inactivation percentage is 99.7% and desired lethality is 2.5D90°C = 18 lethal min. The time to reach this lethality was obtained by trial and error, making different heat penetration tests and calculating the process lethality:

\[
F_0 = \int_0^t 10^{-\frac{t}{z}} dt \tag{3}
\]
The process lethality was estimated as the area under the heat penetration curve \([10^{-T_{\text{d}}}]\) against time. Containers of about 20 L with a metal mesh basket were used for heating the cans in water.

**CRT Process.** The heating water temperature (retort temperature) of the CRT process was 80°C (Barret *et al.* 2005). For generating this CRT profile, cans were subjected to a heating period at 80°C and a cooling period at 6°C, until the food reached 40°C. The time to reach 18 lethal min at 77°C was obtained by trial and error.

**VRT Processes.** Four different retort temperature profiles were designed: downstairs (VRT1): 95, 90, 80 and 6°C; up-down-up (VRT2): 90, 80, 90 and 6°C; ascending ramp (VRT3): from 75 to 93 and 6°C; and upstairs (VRT4): 75, 80, 90 and 6°C. These profiles were generated in water baths at 75, 80, 90 and 95°C. Periods of time at each retort temperature were generated until the food reached 65, 70 and 77°C during heating and 40°C during cooling; they were obtained by trial and error to get isolethal effects (18 lethal min at 77°C). Temperatures for these VRT profiles were selected based on filling temperatures (60°C), inactivation of the target enzyme: PME (77°C), temperature range suggested for the CRT processing of fruit acidic purees (75–95°C) and cooling temperature (6°C), as well as on the implementation of different shape temperature profiles (downstairs, up-down, ascending ramp, upstairs) to characterize their effects on the heat transfer rate for a conduction-heated food. The residence time for each chosen temperature profile during the VRT processing was that required to reach the desired food temperature (65–77°C).

**Quality Parameters.** Total soluble solids of papaya puree were determined according to AOAC methods (AOAC 2012).

Vitamin C content (ascorbic acid) was measured by high-performance liquid chromatography (HPLC) according to Gökmen *et al.* (2000). De-ionized water (20 mL, 12 ± 1°C) was added to 5 g of puree sample, the mixture was homogenized, filtered through cheesecloth and the volume of the recovered liquid was measured. The liquid was sequentially passed through a 0.45-μm Millipore nylon membrane and Sep-Pak C18 cartridge. A 10 μL aliquot of the filtrate was injected into an HPLC-DAD 1100 system (Agilent Technologies, Sta. Clara, CA) and separated by a Symmetry C18 column (5 μm), 3.9 × 150 mm (Waters Company, D.F., Mexico). The mobile phase used was a solution of 25 mM KH2PO4 (The Baker Company, Sanford, ME); the initial flow was 0.2 mL/min for 2 min, then increased up to 4 mL/min in 2 min, remaining constant for 4 min, and finally returning to the initial flow for 1 min. Readings were taken at 270 nm, which represents the maximum ascorbic acid absorption (99.9%) and minimum dehydroascorbic acid absorption (0.1%). Quantification was carried out using a calibration curve prepared with pure ascorbic acid.

The power law model,

\[
\tau = K\gamma^n
\]

was used to obtain the rheological parameters of papaya puree with a dial reading viscometer (Brookfield, HAT, Brookfield Engineering Laboratories, Middleboro, MA), using the methodology reported by Mitschka (1982) that enables the conversion of Brookfield readings to fundamental rheological parameters. Homogenized samples of papaya puree (200 mL) were placed in a beaker (92 mm in height and 64 mm in diameter) and temperature was kept at 20°C. The shear stress (Pa) was calculated from the scale reading (α) and a factor \(k_\alpha\) that depends on spindle number, \(\tau = k_\alpha\alpha\). The shear rate (s⁻¹) was calculated from the rotational speed \(N\) (rpm) and a factor \(k_b\) that depends on spindle number and on the slope \(n\) of a log \(\tau\) versus log \(N\) graph, \(γ = k_bN^n\). The consistency index \((K)\) in Pa·sⁿ and the flow behavior index \((n)\) of puree were obtained from a regression analysis between log \(τ\) and log \(γ\).

Color of papaya puree was measured using a reflectance colorimeter (CR-210; Minolta, Tokyo, Japan) with 10° observation (CIE) and illuminant D65. The mean of three readings on each sample was scored. Three replicates were taken for all quality parameters.

**Selecting the Best Thermal Process**

The selection of the best process profile was achieved by assigning the following relative weights to the response variables: vitamin C content 55%, consistency index 10%, luminosity 10%, and processing time 25%. A higher relative weight for vitamin C content was selected because it is a highly thermosensible nutrient; thus, if vitamin C is well retained, other nutrients would be as well. Consequently, the proposed desirability function was

\[
f_d = \sqrt{\beta_1y_1^3} + \beta_2y_2^3 + \beta_3y_3^3 + \beta_4y_4^3
\]

where the “β” coefficients represent the weighted indices and the “y’s” are the response variables. The highest values of vitamin C content, consistency index and luminosity were desirable. As a shorter processing time was considered desirable, this response was transformed subtracting the processing time from the longest obtained value \((t_{\text{target}} - t)\). These four response variables were normalized to range from 0 to 1, using

\[
y_{n \text{a}} = \frac{y_{\text{highest}} - y_{\text{lowest}} }{y_{\text{highest}} - y_{\text{lowest}}}
\]
Consequently, the highest value of the desirability function (close to unity) indicates the best thermal process for the chosen criteria.

**Statistical Analysis**

A completely random design was used and an analysis of variance was performed for every response variable using the type of profile as the factor. The least significant difference was used as a multiple range test to obtain differences between means.

**RESULTS AND DISCUSSION**

**Physicochemical Properties of Papaya Puree**

Freshly prepared puree of papaya cv. Maradol is a good source of ascorbic acid (Table 1); its color was characterized by yellow and red hues with intermediate luminosity; papaya puree was viscous and had a soluble solid content of 9°Brix. Our results were similar to those reported in the literature (Franke *et al.* 2004; Sancho *et al.* 2010). The vitamin C content of papaya puree was higher than that of lemon, orange, mango, pineapple and tomatoes (Franke *et al.* 2004).

**TABLE 1. PHYSICOCHEMICAL PROPERTIES OF PAPAYA PUREE**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total soluble solids (°Brix)</td>
<td>9.0 ± 1.00</td>
</tr>
<tr>
<td>Color parameters</td>
<td></td>
</tr>
<tr>
<td><em>L</em> <em>a</em></td>
<td>52.9 ± 1.20</td>
</tr>
<tr>
<td><em>a</em></td>
<td>35.0 ± 2.30</td>
</tr>
<tr>
<td><em>b</em></td>
<td>47.0 ± 1.20</td>
</tr>
<tr>
<td>Ascorbic acid (mg/100 g)</td>
<td>70.7 ± 1.50</td>
</tr>
<tr>
<td>Apparent viscosity (Pa·s)</td>
<td>3.5 ± 0.10</td>
</tr>
</tbody>
</table>

Each value represents mean ± SD.

Thermal Processes Applied to Canned Papaya Puree

The coldest spot was located at the geometric center of the can (Fig. 1), which validates conduction as the dominant heat transfer mechanism. This result agrees with that described by Magalhães *et al.* (1999) for canned papaya puree under different thermal process conditions for CRT.

The designed CRT profile was 80°C (39 min) and 6°C (24 min). The processing times for getting isolethal effects in VRT profiles (downstairs [VRT1], up-down-up [VRT2], ascending ramp [VRT3] and upstairs [VRT4]) are shown in Fig. 2. Contrasting with the designed CRT process, all of the isolethal profiles using VRT resulted in lower processing times ($P < 0.05$) (Fig. 2 and Table 2), following the order $\text{VRT1} < \text{VRT2} < \text{VRT3} < \text{VRT4} < \text{CRT}$ (Table 2).

For CRT, the average processing time and accumulated lethality for the heating period corresponded to 61.9 and 53.5% of the total process, respectively. Papaya puree was initially at 60°C, and 95.6% (17.5 lethal min) of total lethality was generated during 41.2% (26 min) of the processing time, from 22.5 to 48.5 min. On the contrary, for the VRT1 profile (downstairs), processing time was reduced by 33.3%. As the initial retort temperature was higher ($\geq 90$C), the reduction in processing time was higher. These results are in agreement with previous reports (Durance 1997) where a reduction in processing time was also found by using an upstairs profile.

From total accumulated lethality, 97.8, 97.2, 98.4 and 96.7% lethality were obtained in 38.1, 36.2, 37.8 and 39.8% of the processing time for VRT1, VRT2, VRT3 and VRT4, respectively. A 97.5% accumulated lethality for the VRT profiles was generated in shorter times compared with CRT.

**FIG. 1. TEMPERATURE HISTORIES OF PAPAYA PUREE AT DIFFERENT THERMOCOUPLE LOCATIONS OBTAINED AT A CONSTANT RETORT TEMPERATURE FOR LOCATING THE COLDEST SPOT**
Vitamin C (Ascorbic Acid)

Papaya puree treated using VRT profiles showed a higher retention of vitamin C (41–65%) than that treated with the CRT profile (27%), compared with freshly prepared papaya puree (Fig. 3). The highest retention ($P < 0.05$) of ascorbic acid was obtained using the VRT4 profile. Conventional CRT treatments applied to horticultural products can generate vitamin C losses of up to 91%, depending on the heat transfer mechanism, pH, handling in preprocessing and heat treatment conditions (Jandhyala et al. 2002; Wijayawardana and Bamunuarachchi 2002). In our study, the VRT4 profile generated a vitamin C loss of 35%. Therefore, VRT processes represent an alternative to CRT with a high potential in the preservation of the quality of thermally processed fruit and vegetables.

Rheological Properties

The flow behavior of papaya puree is shown in Fig. 4. The shear stress was not linearly dependent on shear rate, indicating a non-Newtonian behavior of the puree. The consistency of the puree decreased with an increase in shear rate, determining a shear thinning behavior, which is in accordance with the flow behavior index listed in Table 3. The retention in the consistency index for CRT was 57% compared with fresh papaya puree; meanwhile, the retention using VRT profiles ranged from 63% (VRT3) to 71% (VRT1). A lower consistency index was associated with a lower heat transfer rate to the papaya puree, which may promote pectic hydrolysis, giving rise to low molecular weight polymers that form less viscous solutions. Consequently, a higher heat transfer rate was achieved in VRT profiles, reducing the time for enzyme inactivation. The behavior of consistency index in canned papaya puree is consistent with that reported for fresh papaya puree (Ahmed and Ramaswamy 2004) and mango pulp (Vidal et al. 2004).

Color

The color of papaya puree was better preserved using VRT profiles than CRT (Fig. 5). All of the puree color parameters were lower ($P < 0.05$) than those of fresh papaya puree.

| TABLE 2. PROCESSING TIME AND ACCUMULATED LETHALITY FOR PAPAYA PUREE |
|-----------------------------|----------------|-|-----------------|-----------------|-----------------|-----------------|
| Profiles                  | Processing time (min) | Accumulated lethality (min) |
|                           | Total       | Heating     | Cooling       | Total       | Heating     | Cooling       |
| CRT                       | 63.0 ± 0.5a | 39.0 ± 0.5a | 24.0 ± 0.3a   | 18.3 ± 0.5a | 9.8 ± 0.5a | 8.5 ± 0.4a |
| VRT1                      | 42.0 ± 0.7a | 20.5 ± 0.2a | 21.5 ± 0.2a   | 18.3 ± 0.2a | 3.6 ± 0.2a | 14.7 ± 0.1a |
| VRT2                      | 47.0 ± 0.5a | 25.0 ± 0.7a | 22.0 ± 0.2a   | 18.1 ± 0.1a | 4.2 ± 0.1a | 13.9 ± 0.1a |
| VRT3                      | 49.0 ± 0.2a | 27.8 ± 0.4a | 21.2 ± 0.2a   | 18.3 ± 0.4a | 3.7 ± 0.4a | 14.6 ± 0.2a |
| VRT4                      | 59.0 ± 1.3a | 38.2 ± 0.3a | 20.8 ± 0.5a   | 18.1 ± 0.9a | 5.9 ± 0.9a | 12.2 ± 0.9a |

Constant retort temperature (CRT), variable retort temperature downstairs (VRT1), up-down-up (VRT2), ascending ramp (VRT3) and upstairs (VRT4) profiles, as defined in the Materials and Methods section and Fig. 2. Values are mean ± SD. Different letters in a column indicate significant difference (least significant difference, $\alpha = 0.05$).
Heating of papaya puree induced a darkening process characterized by low luminosity ($L^*$) values, but the change was less drastic in the VRT treatments. The luminosity of the puree obtained from the VRT4 profile was higher ($P < 0.05$) than that from CRT, VRT1 and VRT3. The color saturation (chroma) and hue angle (tone) of papaya puree from VRT2 and VRT3 profiles were higher ($P < 0.05$) than those from CRT and VRT1. Ahmed et al. (2002) reported that the $(a^*b^*)$ product varies linearly with carotenoid content. The $(a^*b^*)$ product in our study was higher ($P < 0.05$) in all VRT profiles compared with CRT; therefore, the $\beta$-carotene retention of the VRT prepared purees should be higher.

### Selection of the Best VRT Thermal Process

Desirability was higher for puree processed by VRT than by CRT in the following decreasing order: VRT4 (0.83) > VRT2 (0.77) > VRT3 (0.72) > VRT1 (0.68) > CRT (0). Thus, the VRT4 profile showed the best global characteristics of puree.

### Table 3. Rheological Parameters of Ostwald de Waele Model for Papaya Puree

<table>
<thead>
<tr>
<th>Papaya puree</th>
<th>$n$</th>
<th>$K$ ($\text{Pa} \cdot \text{s}^n$)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>0.31 ± 0.008$^b$</td>
<td>5.93 ± 0.13$^d$</td>
<td>0.97</td>
</tr>
<tr>
<td>CRT</td>
<td>0.26 ± 0.007$^a$</td>
<td>5.24 ± 0.11$^f$</td>
<td>0.95</td>
</tr>
<tr>
<td>VRT1</td>
<td>0.31 ± 0.005$^a$</td>
<td>6.46 ± 0.10$^b$</td>
<td>0.94</td>
</tr>
<tr>
<td>VRT2</td>
<td>0.33 ± 0.008$^a$</td>
<td>6.31 ± 0.12$^b$</td>
<td>0.94</td>
</tr>
<tr>
<td>VRT3</td>
<td>0.30 ± 0.061$^b$</td>
<td>5.76 ± 0.06$^a$</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Fresh papaya puree (Fresh), constant retort temperature (CRT), variable retort temperature downstairs (VRT1), up-down-up (VRT2), ascending ramp (VRT3) and upstairs (VRT4) profiles. Values are mean ± SD. Different letters in a column indicate significant difference (for flow behavior index, least significant difference [LSD] = 7.9 × 10$^{-3}$; for consistency index, LSD = 0.12 Pa·s$^n$, $\alpha = 0.05$).
and the highest vitamin C retention (65%) compared with that from CRT (27%) in spite of the shortest processing time (42 min) obtained in the VRT1 profile (downstairs).

**CONCLUSIONS**

The use of VRT profiles for canning of papaya puree shortened the processing time and enhanced the quality retention compared with conventional thermal processing (CRT). In the VRT processes, papaya puree retained up to 65% vitamin C, in relation to freshly prepared puree, whereas this value was only 27% for puree using a CRT. Processing time in the VRT profiles was reduced to 33.3% compared with a CRT. The highest value of desirability function was obtained from the upstairs profile (VRT4). The VRT processes of acidic fruits are less drastic and produce foods with high nutritional quality; thus, the technological challenge is the substitution of the common industrial retort equipment for reservoirs at different temperatures for the application of a specific product designed VRT profile. Processing of papaya puree, as well as other conduction-heated foods, using VRT is highly recommended, rendering microbiological safety and improved nutritional value.

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