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*Original Article*

# Effect of indirect ohmic heating on quality of ready-to-eat pineapple packed in plastic pouch♣

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## Abstract

Ready-to-eat fruits packed in sealed containers are highly perishable due to their intrinsic characteristics and lack of full thermal process. Ohmic heating has the advantages of rapid liquid heating through electrical current. The aim of this research was to investigate the effect of indirect ohmic heating on pH, total soluble solids, polyphenol oxidase activity, color and texture of ready-to-eat pineapple packed in a polypropylene pouch with 1% calcium chloride and 0.3% ascorbic acid packing solution. The pre-packed sample in a pouch was placed in the ohmic heating jar filled with 0.5% sodium chloride ohmic heating solution which was then ohmic heated at different voltage gradients (20, 30, 40 V/cm), to different packing solution temperatures (60, 70, 80°C) for 60s. Samples were kept at 4°C for quality measurement. It was found that browning index of ready-to-eat pineapple treated with 20 V/cm at 80°C, 30 V/cm at 70°C and 80°C, 40 V/cm at 80°C did not change during 12 days cold storage ($p>0.05$). Polyphenol oxidase was inactivated when the temperature of the pineapple was 62°C or higher. After 10 days at 4°C, the pineapple heated with 30 V/cm at 70°C had much higher firmness than the un-heated sample kept at the same storage condition. Indirect ohmic heating of pre-packed ready-to-eat pineapple in polypropylene pouch with 30 V/cm at 70°C packing solution temperature for 60s could be used as minimal heating methods to maintain the quality of ready-to-eat fruits in 12 days at 4°C.

**Keywords:** ohmic heating, ready-to-eat pineapple, quality, minimally process, plastic pouch

## 1. Introduction

Fresh-cut fruit products are fruits that have been washed, peeled, sliced, chopped or cut prior to being packed for consumption (Barry-Ryan and O'beirne, 1998). Minimal process can be applied to this fresh-cut or fresh produce to create ready-to-eat (RTE) fruit product which has fresh-like quality and appearance with extended shelf life. Modern customer demand for RTE products is increasing as a means of saving time without abandoning a healthy diet. The growing of the fresh pineapple market is linked to recent development of fresh-cut and other pineapple products (FAO, 2009). Cut pineapple ranked the highest of all tropical fruit in quantity and dollars sold in value-added category for US fresh fruit in supermarkets (Cook, 2007). Rapid deterioration of fresh-cut fruit limits its shelf life. Peeling and cutting exacerbate the problems as metabolic activity increases and cellular compartmentation is lost. These bring about enzyme and substrate interactions causing product browning, softening, microbial deterioration, and off-flavor and odor development (Ahvenainen, 1996). Consequences of mechanical injuries to RTE fruits accelerate enzymatic browning from a group of enzymes such as polyphenol oxidases (PPO). PPO have been reported to occur in all plants and exist in particularly high amounts in mushroom, banana, apple, lettuce, and pineapple (Yoruk and Marshall, 2003; Wuyts *et al.*, 2006;

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Gawlik-Dziki *et al.*, 2008, Manzocco *et al.*, 2009). Minimal heat treatment can be applied to RTE product to control enzymatic browning, firmness changes, and decay (Brecht, 1993).

Ohmic heating is a process in which heat is internally generated within food by passing an alternating electric current through the food (Wang and Sastry, 1993). Most foods contain ionized molecules such as salts and acids, hence electric current can move through the food and generate the heat inside (Palaniappan and Sastry, 1991b). The advantage of ohmic heating for particulate foods is a more uniform heating of both liquid and solid phases as compared to conventional heating. In ohmic heating, heating rate of food expressed as the temperature increase per unit of time (°C/s) depends on electric current and voltage applied to the food. Electrical conductivity (ó) of food has been pointed out as a critical parameter to the understanding of food heating rate under ohmic heating (Palaniappan and Sastry, 1991b). Electrical conductivity of most food materials subjected to ohmic heating is a linear function of temperature (Palaniappan and Sastry, 1991b). Research on ohmic applications in fruits and vegetables has been undertaken by several authors (Palaniappan and Sastry, 1991a; Sastry and Palaniappan, 1992; Castro *et al.*, 2004b; Legrand *et al.*, 2007), but little has been done on RTE fruit (Meldrum *et al.*, 2006). Application of ohmic heating to solid or large fruit particles packed in a pouch is not common due to the impairing effect of plastic pouch on electrical current passing to the pre-packed fruit. However, heating of pre-packed RTE fruit in an ohmic system can be employed to take the advantage of rapid ohmic heating effect on the heating medium which in turn rapid heats the pre-packed sample. Advantages of indirect ohmic heating over conventional heating on microbial growth of RTE pineapple packed in plastic pouch, and the energy consumption was demonstrated by Hoang *et al.* (2013). This indirect ohmic heating of pre-packed RTE fruits offers an alternative method to minimal process technique. The aim of this study was to determine the effect of voltage gradient and temperature of packing solution on pH, total soluble solids, PPO activity, color, and texture of RTE pineapple packed in plastic pouch treated by indirect ohmic heating and then kept at 4°C.

## 2. Materials and Methods

### 2.1 Sample preparation

Fresh pineapple, smooth cayenne cultivar, was bought from wholesale fruit market in Rungsit district, Bangkok, Thailand, and stored at 10±1°C overnight prior before processing. The fruits had been harvested on the previous day with not more than 15% of the eyes were yellow. All fruits were within the range of 13.8±0.3 °Brix and a pH of 3.8±0.1. Cutting boards, knives, working surface were cleaned with 200 ppm sodium hypochlorite solution before use (Montero-Calderon *et al.*, 2008). Fruits were peeled with a pouch thickness of 95 mm, and cored by 25 mm diameter stainless steel cylindroid cutter, then cut into 1 cm thickness slices, and divided into six 10-g wedges per slice. A portion of 150-g RTE pineapple wedges was placed in plastic zip lock pouch filled with 150 ml of packing solution at ratio 1:1 to weight of RTE pineapple and volume of packing solution. Polypropylene (PP) pouches (180 x 280 mm), 0.055 mm thickness supplied by Hungchor Supplier, Bangkok, Thailand, were used. The packing solution was 1% calcium chloride (Fisher Scientific, Germany) + 0.3% ascorbic acid (Aldrich, Germany) solution (adapted from Martinez-Ferrer *et al.*, 2002). The ohmic treated sample was packed with this solution (1% calcium chloride + 0.3% ascorbic acid). All procedures were conducted in a sanitary processing room at 18°C.

### 2.2 Experimental setup

Indirect ohmic heating is an ohmic heating process applied to fresh pineapple wedges that were packed in PP plastic pouch. The RTE fruits were ohmic heated through the pouch. A diagram of the indirect ohmic heating setup and data acquisition system is shown in Figure 1. The ohmic heating system consisted of a transducer, a data logger (DX 1012, Yokogawa, Japan) and multimeter (Fluke 8088A, Fluke, USA) connected to a computer for temperature, voltage, and electrical current data collection. The system included fuses and an uninterruptible power supply (UPS) to stabilize the power supply. The circuit was linked to ohmic heater electrodes. The setup of indirect ohmic heater is shown in Figure 2. The ohmic heater included a glass jar (Norita Glass, Thailand) 300 mm in height and 200 mm in diameter with an acrylic cover attached. The 500 mm diameter curve 316L stainless steel electrodes were attached to the acrylic cover with 64 mm gap between the 2 electrodes. Ohmic heating medium was a liter of 0.5% sodium chloride solution adjusted to pH 5.5 with 0.2M citric acid.

The pre-packed RTE fruit pouch was placed in the center between the electrodes, with 15 mm distance from each electrode. The ohmic heating medium whose level was matched to the level of packing solution inside the pouch was

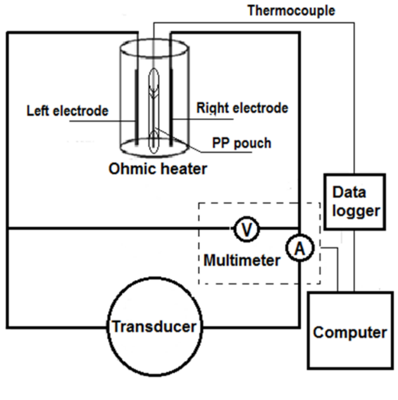

Figure 1. Schematic diagram of the ohmic heating unit.

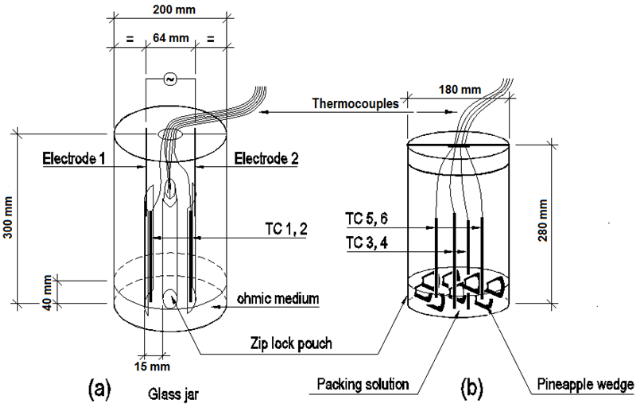

Figure 2. Schematic diagrams of indirect ohmic heating system (a), and RTE pineapple packed in plastic pouch (b).

filled into the jar. The ohmic heating medium level was kept constant in all experiments. T-type thermocouple class A (W. Dhavepatana Co., Thailand) was used. Two thermocouples ($TC_1$, $TC_2$) were placed in the ohmic heating medium close to each electrode. Two thermocouples ($TC_3$, $TC_4$) were immersed in the packing solution inside the pouch. Two thermocouples ($TC_5$, $TC_6$) were inserted into pineapple wedges at geometries center. Samples were ohmic heated by 50 Hz alternating current, and the voltage was controlled by an electrical transducer. Voltage, current and temperature were recorded at 5 s interval using FlukeView Form 3.6 and DAQLOGGER Manager 7.1 though the multi-meter and data logger, respectively.

### 2.3 Experiment design

RTE pineapple wedges were indirect ohmic heated at different voltage gradients, i.e., 20, 30, and 40 V/cm to the packing solution temperature of 60, 70 and 80°C, and then held for 60s. The heated pouch was immediately removed from the system and cooled down to 10°C in ice water. The RTE pineapple samples were heated at each combination of voltage gradient and packing solution temperature with two replicates. Samples were stored at 4°C until used. For control, the sample was packed and kept in the same solution (1% calcium chloride + 0.3% ascorbic acid) as used for the ohmic heated sample. The pH, total soluble solids, PPO activity, color and textural firmness were measured before and after the indirect ohmic heat treatments.

### 2.4 Measurement

#### 2.4.1 pH and total soluble solids

RTE pineapple (50g) was homogenized using a Panasonic blender, Japan, and filtered (Whatman paper No.1) for clear juice. Total soluble solids (TSS) content was determined using an Atago RX-1000 refractometer (Atago Company Ltd., Japan). pH was directly measured using a pH meter (model 210A, Orion Research, USA).

#### 2.4.2 PPO assay

PPO activity was determined according to the methods used by (Rojas-Grau *et al.*, 2008; Montero-Calderón *et al.*, 2009) with some modification. A 50 g of pineapple was mixed with a Mcllvaine buffer solution (1:1) at pH 6.5 containing 1% vinylpolypyrrolidone (Fluka, Sigma Aldrich, Germany). The mixture was blended and homogenized for 30s and centrifuged at 9,100 x g for 30 min at 4°C (Sorvall RC-6 Plus centrifuge, roto SLA 1500, Thermal Scientific, Germany). The supernatant was collected and filtered through Whatman No.1 paper, and the resulting solution constituted the enzymatic extract. Enzyme activity was measured by adding 75µL of the extract to 3 mL of 0.05 M catechol (Sigma Aldrich, Germany) in a 4.5 mL quartz cuvette (1 cm path length) with absorbance reading by a GENESYS™ 10S UV-Vis Spectrophotometers, Thermo Scientific, Germany. Changes in the absorbance at 420 nm were recorded every 5s up to 3 min from the time the enzyme extract was added. One unit of enzyme activity is defined as the amount of the enzyme that causes an increase in absorbance of 0.001/min at 25 °C.

#### 2.4.3 Color

Tri-stimulus reflectance color was measured by a CM 3500d Spectrophotometer (Konica Minolta, Japan). CIE 1976 scale with L*, a*, and b* values were obtained using a D65 illuminant and 10° observer angle with a white standard tile as the reference system. Six pineapple wedges were measured for color on two sides. Browning index (BI) was calculated using L*, a*, and b* values (Saricoban and Yilmaz, 2010) according to equation (1).

$$\mathrm{BI} = \frac{\left[100*\left(x-0.31\right)\right]}{0.17} \tag{1}$$

Where: $x = \dfrac{a*+1.75\,L*}{5.645\,L*+a*-3.012\,b*}$

Smaller BI value indicated the higher browning appearance. Change in browning index (“BI) was calculated as the difference between BI of the fresh (or first day) RTE pineapple and the BI of treated RTE pineapple at specified days of storage at 4°C.

#### 2.4.4 Texture

Textural firmness of RTE pineapple was measured using a Texture Analyser (TA-XT2, Stable Micro Systems, UK) equipped with a cylindroid P6 probe (6 mm diameter), with a 5 kg load cell (Montero-Calderon *et al.*, 2008) with some modification. The pineapple wedge was placed on the platform of the texture analyzer, and the firmness test was

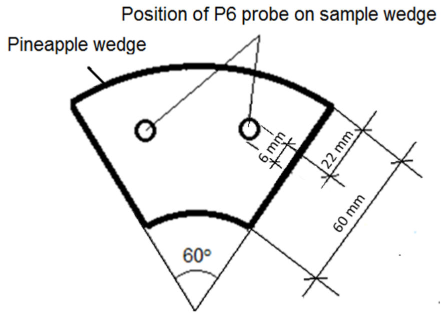

Figure 3. Texture measure position of pineapple wedge

performed at two points on the surface of sample (Figure 3). The measurement setting was 10 mm/s pre-test speed, 5 mm/s test speed, 10 mm/s post-test speed, 4 mm/s rupture test distance, 5 mm distance, 5g trigger force strain, at 25°C. Twelve wedges were measured at 2 points on each wedge.

### 2.5 Statistical analysis

Statistical comparisons were made by one-way analysis of variance (ANOVA) followed by a Duncan multiple range test using SPSS 15.0 statistical software. Differences were considered significant when the p-value was $< 0.05$.

## 3. Results and Discussion

### 3.1 pH and total soluble solids

pH of RTE pineapple decreased significantly (pH 3.4-3.5) after indirect ohmic heating as compared to fresh fruit (pH 3.8) ($p<0.05$). This was likely due to the acidity of 0.3% ascorbic acid in the packing solution (pH 2.6). Calcium chloride and ascorbic acid was used to maintain textural firmness and to retard oxidation of the color according to Martinez-Ferrer *et al.* (2002). However, there were no differences in pH among all of the ohmic heated samples at different voltage gradient and at different packing solution temperatures (Table 1). Different indirect ohmic heating conditions did not affect pH of the RTE fruits.

TSS content of fresh and treated pineapple is shown in Table 1. TSS content of the samples treated with 20 V/cm at 60°C and 40V/cm at 60°C of packing solution temperature had the lowest change as compared to the other treatments ($p<0.05$). Heat treatment often damages the cellular structure of fruits and accelerates loss of TSS from the fruit. Minimum use of heat was preferred for RTE fruit product.

### 3.2 PPO activity

PPO activity of RTE pineapple heated with various voltage gradients to different temperatures of packing solution is shown in Table 2. PPO of fresh pineapple was 27.25 enzyme units. Drastic decrease in the PPO activity by indirect ohmic heating is demonstrated in Table 2. There was no PPO activity detected in samples treated with 20V/cm at 70 and 80°C; 30V/cm at 70 and 80°C; 40V/cm at 80°C. Temperatures of the RTE pineapple were recorded during the indirect ohmic heat treatment. It was shown that PPO in the RTE pineapple could be inactivated when fruit temperature was 62.1°C or higher. Thermal heat transfer from the rapid heating up of ohmic heating medium to the packing solution in the pouch and then to the fruit was likely the main cause for PPO inactivation. We did not detect electrical current higher

Table 1. pH and total soluble solids (TSS) of ready-to-eat pineapple packed in polypropylene pouch which was ohmic heated under different voltage gradient and temperature of packing solution

| Voltage gradient (V/cm) | Temperature of packing solution(°C) | pH | TSS (°Brix) |
|---|---|---|---|
| Fresh pineapple | | $3.8^{a}\pm0.1$ | $13.8^{a}\pm0.3$ |
| 20 | 60 | $3.5^{b}\pm0.1$ | $9.8^{bc}\pm0.3$ |
| 20 | 70 | $3.4^{b}\pm0.1$ | $8.7^{ef}\pm0.1$ |
| 20 | 80 | $3.5^{b}\pm0.1$ | $8.3^{f}\pm0.1$ |
| 30 | 60 | $3.5^{b}\pm0.1$ | $9.2^{de}\pm0.0$ |
| 30 | 70 | $3.5^{b}\pm0.1$ | $8.9^{de}\pm0.1$ |
| 30 | 80 | $3.4^{b}\pm0.1$ | $8.4^{f}\pm0.3$ |
| 40 | 60 | $3.5^{b}\pm0.1$ | $10.2^{b}\pm0.3$ |
| 40 | 70 | $3.5^{b}\pm0.1$ | $9.3^{cd}\pm0.1$ |
| 40 | 80 | $3.5^{b}\pm0.1$ | $8.7^{ef}\pm0.1$ |

Mean ± standard deviation followed by different superscript within each column are significantly different ($p < 0.05$)

Table 2. Polyphenol oxidase (PPO) activity, total time of treatment, and temperature of ready-to-eat pineapple packed in polypropylene pouch which was ohmic heated under different voltage gradients and temperatures of packing solution

| Voltage gradient (V/cm) | Temperature of packing solution(°C) | Total time of treatment[1](s) | Temperature of pineapple fruit(°C) | PPO activity (Unit) |
|---|---|---|---|---|
| Fresh pineapple | | - | - | 27.25±3.54[2] |
| 20 | 60 | 505±60 | 50.4±3.0 | 6.50±0.71 |
| 20 | 70 | 795±46 | 68.0±0.9 | Not detected |
| 20 | 80 | 1000±33 | 78.9±1.0 | Not detected |
| 30 | 60 | 322±30 | 57.8±0.8 | 8.21±0.00 |
| 30 | 70 | 365±13 | 62.1±1.3 | Not detected |
| 30 | 80 | 410±40 | 72.1±6.2 | Not detected |
| 40 | 60 | 188±8 | 50.9±3.3 | 10.51±2.12 |
| 40 | 70 | 232±19 | 60.0±6.6 | 3.41±0.82 |
| 40 | 80 | 263±23 | 71.7±4.3 | Not detected |

[1] Time in seconds to reach the designated packing solution temperature and then held for 60 seconds.
[2] Mean ± standard deviation

than 1 mA in the packing solution (inside the pouch) during the experiment. The effect of ohmic heating, i.e., small electrical current and electrical field, through the plastic pouch, if any, was under investigation.

According to several authors, inactivation of PPO by heat treatment is the most effective method to control enzymatic browning (McEvily *et al.*, 1992; Sapers 1993). Chutintrasri and Noomhorm (2006) reported that PPO in pineapple puree heated by water bath lost over 50% of its activity following 20 min exposure at 60°C. In our indirect ohmic heating the total time of treatment was about 6 min (Table 2) for the pineapple to reach the temperature of 62.1°C by 30V/cm voltage gradient at 70°C packing solution temperature. The higher the voltage gradient the faster the RTE pineapple reached critical temperature, e.g. about 3.9 min for 40V/cm at 70°C. Inactivation of PPO could be done in shorter time with higher voltage gradient used in the ohmic treatment; however, other quality factors such as color, texture must be considered for optimization of RTE fruit quality.

### 3.3 Browning index

Changes in color parameter (L*, a* and b* value) of indirect ohmic treatment RTE pineapple in 12 days storage at 4°C were calculated as the browning index (BI) value. Table 3 indicates the change in BI value (ΔBI) of RTE pineapple treated by indirect ohmic heating with various voltage gradients at different packing solution temperatures. BI of all indirect ohmic heated RTE pineapple at the first day of storage was not significantly different ($p<0.05$) from the fresh pineapple. Significant color changes in samples were observed after 12 days of storage. ΔBI was prominent (highest value) for the fresh sample stored under the same conditions. This suggested the action of enzymatic browning occurred in the un-heated sample. Palou *et al.* (1999) reported that the increase in ΔBI suggested the PPO enzymatic browning took places in banana puree.

At 12 days of storage, indirect ohmic heating by 20 V/cm at 80°C, 30V/cm at 70°C, 30V/cm at 80°C, and 40V/cm at 80°C had the lowest change in ΔBI. These treatments corresponded to the absence of PPO activity as indicated in Table 2. Hence it was clearly seen that in our indirect ohmic heating samples that browning occurred mainly due to PPO activity. It is noteworthy that browning still occurred in the 20V/cm at 70°C despite the absence of the PPO, thus suggesting the possibility of other enzymatic browning reactions in the sample. Although RTE pineapple treated with 40V/cm at 80°C had low ΔBI value, the fruit sample lost its yellow color appearance and turned to whiteness, which was not accepted by general consumer. Therefore, the 3 indirect ohmic heating conditions of 20V/cm at 80°C, 30V/cm at 70°C, and 30V/cm at 80°C were the candidates for the potential applications in RTE pineapple samples.

### 3.4 Texture

Changes in textural firmness of RTE pineapple subjected to various indirect ohmic heating treatments then stored at 4°C are shown in Table 4. Significant decrease in firmness due to heating effect was observed in all treatments as compared to the fresh sample. However, after 10 days cold storage all heated samples exhibited lower changes in textural firmness (ΔFirmness) whereas the unheated sample had the greatest decrease in the firmness as compared to the first day of storage. At the 10 days of storage the firmness of the

Table 3. Browning index of ready-to-eat pineapple packed in polypropylene pouch which was ohmic heated under different voltage gradients and temperatures of packing solution then stored at 4°C

| Voltage gradient (V/cm) | Temperature of packing solution(°C) | Browning Index[1] | | | Δ BI[2] |
|---|---|---|---|---|---|
| | | Days at 4°C | | | |
| | | 1 | 4 | 12 | |
| Fresh pineapple | | $28.1^{abA}\pm0.5$ | $21.8^{cB}\pm1.5$ | $16.7^{fC}\pm0.4$ | $11.6^{d}\pm0.9$ |
| 20 | 60 | $26.3^{bA}\pm1.0$ | $24.3^{bcA}\pm0.1$ | $19.2^{deB}\pm0.4$ | $7.1^{c}\pm1.3$ |
| 20 | 70 | $26.7^{bA}\pm0.9$ | $26.1^{abA}\pm0.2$ | $21.9^{cB}\pm0.5$ | $4.8^{b}\pm0.5$ |
| 20 | 80 | $28.3^{abA}\pm1.5$ | $25.9^{abA}\pm0.8$ | $27.4^{bA}\pm0.5$ | $0.9^{a}\pm2.0$ |
| 30 | 60 | $26.7^{bA}\pm1.6$ | $26.6^{abA}\pm1.2$ | $17.7^{efB}\pm1.2$ | $9.0^{c}\pm0.4$ |
| 30 | 70 | $27.6^{abA}\pm0.4$ | $27.1^{abA}\pm1.2$ | $26.6^{bA}\pm0.7$ | $1.0^{a}\pm0.3$ |
| 30 | 80 | $26.8^{bA}\pm2.6$ | $27.5^{abA}\pm1.8$ | $27.4^{bA}\pm0.1$ | $-0.6^{a}\pm2.7$ |
| 40 | 60 | $28.1^{abA}\pm0.8$ | $26.4^{abA}\pm0.9$ | $20.7^{cdB}\pm0.6$ | $7.4^{c}\pm0.2$ |
| 40 | 70 | $28.5^{abA}\pm1.8$ | $25.5^{abB}\pm1.5$ | $19.6^{dC}\pm1.2$ | $8.9^{c}\pm0.6$ |
| 40 | 80 | $29.8^{aA}\pm1.1$ | $27.9^{abA}\pm0.7$ | $29.1^{aA}\pm0.6$ | $0.7^{a}\pm0.5$ |

[1] Mean ± standard deviation followed by different lowercase superscript within each column, and uppercase superscript within each row are significantly different ($p < 0.05$)

[2] Change in Browning Index, Δ BI = BI of RTE pineapple at 1st day - BI of treated RTE pineapple at 12th day

Table 4. Textural firmness of ready-to-eat pineapple packed in polypropylene pouch which was ohmic heated under different voltage gradient and temperature of packing solution then stored at 4°C

| Voltage gradient (V/cm) | Temperature of packing solution(°C) | Firmness[1] (N) | | | Δ Firmness[2] (N) |
|---|---|---|---|---|---|
| | | Days at 4°C | | | |
| | | 1 | 5 | 10 | |
| Fresh pineapple | | $7.50^{aA}\pm0.09$ | $6.55^{aB}\pm0.05$ | $4.74^{abC}\pm0.31$ | $2.76^{c}\pm0.40$ |
| 20 | 60 | $5.99^{eA}\pm0.09$ | $5.58^{bA}\pm0.09$ | $4.66^{abB}\pm0.10$ | $1.33^{ab}\pm0.19$ |
| 20 | 70 | $5.96^{efA}\pm0.03$ | $4.92^{deB}\pm0.02$ | $4.65^{abC}\pm0.27$ | $1.31^{ab}\pm0.30$ |
| 20 | 80 | $5.83^{fgA}\pm0.02$ | $4.80^{eB}\pm0.12$ | $4.31^{bC}\pm0.28$ | $1.52^{ab}\pm0.25$ |
| 30 | 60 | $6.93^{bA}\pm0.01$ | $5.29^{cB}\pm0.04$ | $4.56^{abB}\pm0.03$ | $2.37^{c}\pm0.04$ |
| 30 | 70 | $6.23^{dA}\pm0.06$ | $5.55^{bB}\pm0.14$ | $4.91^{aB}\pm0.07$ | $1.32^{ab}\pm0.11$ |
| 30 | 80 | $5.22^{hA}\pm0.08$ | $5.02^{cB}\pm0.06$ | $4.22^{bC}\pm0.25$ | $1.00^{ab}\pm0.33$ |
| 40 | 60 | $6.43^{cA}\pm0.02$ | $5.55^{bB}\pm0.09$ | $4.72^{abC}\pm0.02$ | $1.71^{b}\pm0.01$ |
| 40 | 70 | $5.80^{gA}\pm0.00$ | $4.93^{deB}\pm0.07$ | $4.31^{bB}\pm0.42$ | $1.49^{ab}\pm0.42$ |
| 40 | 80 | $5.05^{iA}\pm0.06$ | $4.32^{fB}\pm0.00$ | $3.46^{cC}\pm0.05$ | $1.59^{ab}\pm0.12$ |

[1] Mean ± standard deviation followed by different lowercase superscript within each column, and uppercase superscript within each row are significantly different ($p < 0.05$)

[2] Change of textural firmness: Δ Firmness (N) = Firmness of RTE pineapple at 1st day – Firmness of treated RTE pineapple at 10th day storage at 4°C

indirect ohmic heating RTE pineapples at 20V/cm at 80°C and 30V/cm at 80°C (4.31 and 4.22 N, respectively) was significantly lower ($p<0.05$) than that of the 30V/cm at 70°C sample (4.91N). This was most likely due to higher temperature effects on softening of the fruit texture as can be seen by the temperature of the fruits in Table 2. RTE pineapples at

20V/cm at 80°C and 30V/cm at 80°C had reached the fruit temperature of 78.9 and 72.1°C whereas the 30V/cm at 70°C sample had only reached 62.1°C. Comparing these 3 potential indirect ohmic treatments minimal heat treatment, at 30V/cm at 70°C offered the higher TSS, higher firmness with comparable color changes and complete inactivation of the PPO compound with the other treatments (20V/cm at 80°C and 30V/cm at 80°C). In addition, the RTE pineapple of this 30V/cm at 70°C treatment had the similar textural firmness (Table 4), and better color (higher BI, less browning, Table 3) as compared to the fresh sample (unheated) stored at the same condition for the same time period.

## 4. Conclusion

According to the results obtained in this study, application of indirect ohmic heating at 30 V/cm voltage gradient at 70°C packing solution temperature and then holding for 60s is the recommended for indirect ohmic heating for RTE pineapple packed in PP pouches. This indirect ohmic treatment was chosen based on the optimized quality of pH, TSS, color changes, inactivation of PPO and textural firmness of the sample stored at 4°C as compared the other conditions as well as to the control (unheated sample). Indirect ohmic heating therefore offers a potential application for minimally processed RTE pineapple pre-packed in plastic pouch with good visual appearance and firmness.

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