**A THESIS FOR THE DEGREE OF MASTER OF SCIENCE**

# Effect of a 915 MHz microwave system on inactivation of foodborne pathogens in tomato products

토마토 제품 내 병원성 미생물 저감화에 대한

915 MHz 마이크로파 시스템의 효과

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석사학위논문

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이 논문을 석사학위 논문으로 제출함

2014 년 8 월

서울대학교 대학원 농생명공학부

성 혜 정

성혜정의 석사 학위논문을 인준함

2014 년 8 월

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# ABSTRACT

Microwave heating is one of popular thermal technology for food processing. Unlike conventional heating methods, in microwave heating, heat is volumetrically generated inside the food by influence of dipolar and ionic components in an oscillating electric field. Therefore, efficient food processing with relatively less quality change is possible. However, to our knowledge, very few research studies have reported on the bactericidal effect of 915 MHz microwave systems against foodborne pathogens in foods. Therefore, in this study, we investigated the effect of a 915 MHz microwave system with different power levels on the inactivation of *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes* in tomato processed products; tomato paste and salsa. Also, changes in color, pH, and lycopene content of tomato products after microwave heating treatment were studied. In the present work, we attempted to explore the optimal treatment power level-time conditions for application of a 915 MHz microwave system to each tomato product. Tomato paste or salsa inoculated with the three pathogens was

treated with microwave heating at different power levels: 1.8, 2.1, 2.4, 3.0, 3.6 kW and 1.2, 1.8, 2.4, 3.6, 4.8 kW, respectively. Time-temperature profiles were obtained at both center and side portion of a container filled with tomato products for all power levels. Tomato paste and salsa were heated by microwave until the center temperature reached 100°C and 90°C, respectively. As power level for treatment increased, the time needed for the center portion to achieve the target temperature decreased. There was a temperature difference between center and side portions during treatment, but it generally decreased as power level increased within designated range. In all samples, populations of surviving pathogens decreased when treatment time increased at the designated power level. Also, higher power levels of microwave heating allowed certain levels of pathogens to be effectively inactivated in less time. After microwave heating treatment, populations of all three kinds of pathogens were reduced by detection limit (1.0 log CFU/g) in tomato paste. Population reductions of 5.17-6.21 log CFU/g, 5.76-6.10 log CFU/g, and 4.51-4.84 log CFU/g were observed in salsa for *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes*, respectively. We confirmed that

microwave heating did not have a great effect on color values ($L^*$, $a^*$, and $b^*$), pH, and lycopene content of tomato products. $L^*$ values of tomato paste were significantly changed after treatment compared to control, but the difference was not that large. And in the case of lycopene content of salsa, only samples treated with 4.8 kW, which had 67.72±1.65 mg/kg of lycopene, showed significant difference when compared to control which had 75.47 mg/kg. In conclusion, microwave heating of tomato paste and salsa with a 915 MHz system could be an alternative pasteurization intervention in that it can improve microbiological safety while simultaneously maintaining overall organoleptic quality.

***Keywords:*** **Microwave heating; 915 MHz microwave system; Foodborne pathogen; Tomato products**

***Student Number:*** **2012-23381**

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# I. INTRODUCTION

Over the past two decades, the demand for tomato-based products such as tomato juice and ketchup has increased and contributed to greatly increased of consumption of tomatoes worldwide (Vallverdu-Queralt et al., 2011). Tomato products contain a variety of nutrients such as lycopene, flavonoids, carotene, vitamin C, vitamin E, and folate and their health benefits have been well noted by many clinical studies (Clinton, 1998; Walfisch et al., 2007; Willcox et al., 2003). About 80% of tomatoes produced in U.S.A. are used to manufacture a number of processed products (Thakur et al., 1996). Tomato paste is one of tomato processed products and results from the concentration of tomato pulp that skins and seeds of tomato are removed (Hayes et al., 1998). It is widely used to prepare various tomato processed products (Buttery et al., 1990). One of example is salsa, a Mexican sauce which has become a popular food throughout the world, which usually consists of multiple ingredients such as fresh tomatoes, jalapeño peppers,

onions, coriander leaves, and seasonings (Franco et al., 2010; Kendall et al., 2013; Ma et al., 2010). According to recent statistics, 36% of households frequently consume salsa as a condiment in the U.S.A. (Neetoo and Chen, 2012).

In the past, acidic or acidified foods which have a pH lower than 4.6, like tomato paste and salsa (pH<4.0), were considered safe from a microbiological aspect. However, there have been several foodborne illness outbreaks related to consumption of tomato related products in the United States (Besser et al., 1993). According to a report by Centers for Disease Control and Prevention (CDC) (2011), consumption of tomatoes contaminated with *Salmonella* spp. resulted numerous outbreaks of foodborne disease between 2002 and 2009. And salsa was implicated in 70 foodborne outbreaks which resulted in 2,280 cases of illness between 1990 and 2006 (Franco and Simonne, 2009). Also, a *Salmonella enterica* serovar Saintpaul outbreak reported by the US Food and Drug Administration (US FDA) was caused by consumption of salsa containing tomatoes, coriander leaves, and jalapeño peppers (US FDA, 2008). Up through the present time,

the consumption of fresh produce has been increasing due to year-round availability through global distribution (Beuchat and Ryu, 1998). The potential for raw vegetables to harbor foodborne pathogens such as *Salmonella, Escherichia coli* O157:H7, and *Listeria monocytogenes* is frequently detailed in numerous reports (Harris et al., 2003). Therefore, tomato paste and salsa prepared from fresh produce can be a vehicle of these representative foodborne pathogens.

Various non-thermal technologies (Bari et al., 2003; Besser et al., 1993; Franco and Simonne, 2009; Neetoo and Chen, 2012; Thakur et al., 1996) have been studied for improving the microbiological safety of foods including tomato related products. However, thermal processing is still the most widely-used method for manufacturing processed tomato products by the food industry (Apaiah and Barringer, 2001). For several decades, microwave heating has been used as one thermal treatment method for processing many foods. In microwave heating, unlike conventional heating methods, heat is generated inside the food volumetrically by microwave energy. Therefore, foods can be processed with higher efficiency, in shorter

time, and with fewer changes in flavor and nutritional qualities compared to conventional heating (Vadivambal and Jayas, 2010; Zhu et al., 2007). Microwave heating of food is influenced by both dipolar and ionic components existing in foods. Rotating dipolar water molecules in foods absorb microwave energy and cause friction among surrounding molecules during realignment in an oscillating electric field. Through friction the energy is converted into heat, in other words, volumetric heating is achieved in food. Additionally, microwave heating results from the migration of ions in the food when a high frequency oscillating electric field is provided (Datta and Davidson, 2000; Ohlsson and Bengtsson, 2001).

There are two representative frequencies for microwave processing of food. A frequency of 2,450 MHz is used in both domestic and industrial microwave systems, and a frequency of 915 MHz is mainly utilized in industrial microwave equipment (Datta and Davidson, 2000). However, most industrial microwave systems operate at a frequency of 915 MHz in the U.S.A. because of relatively high penetration depth (Coronel et al., 2008). There have been many research studies (Cañumir et al., 2002; Gentry and

Roberts, 2005; Lu et al., 2011) directed toward inactivation of foodborne pathogens by using 2,450 MHz microwave systems. However, to our knowledge, few research studies have reported on the inactivation effect of 915 MHz microwave systems against foodborne pathogens, especially in fruit and/or vegetable foods. Therefore, in this study, we investigated the effect of a 915 MHz microwave system with different power levels on the inactivation of *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes* in tomato paste and salsa. Also, changes in color, pH, and lycopene content of those tomato products after microwave heating treatment were studied.

# II. MATERIALS AND METHODS

### *2.1. Bacterial cultures and inocula*

Three strains each of *E. coli* O157:H7 (ATCC 35150, ATCC 43889, ATCC 43890), *S.* Typhimurium (ATCC 19585, ATCC 43971, DT 104), and *L. monocytogenes* (ATCC 19111, ATCC 19115, ATCC 15313) were obtained from the Department of Food and Animal Biotechnology culture collection at Seoul National University (Seoul, South Korea). Stock cultures were prepared by mixing 0.7 ml of 24 h stationary phase cultures grown in tryptic soy broth (TSB; Difco, Becton Dickinson, Sparks, MD, USA) with 0.3 ml of 50% glycerol and storing at –80°C. Working cultures for experiments were streaked onto tryptic soy agar (TSA; Difco), incubated at 37°C for 24 h, and stored at 4°C.

For preparation of inocula, each strain of the three pathogens was cultured in 5 ml of TSB at 37°C for 24 h, harvested by centrifugation at 4000

g for 20 min at 4°C, and washed three times with sterilized 0.2% peptone water (Bacto, Sparks, MD). The final pellets were resuspended in 0.2% sterile peptone water, corresponding to approximately $10^8$-$10^9$ CFU/ml. Mixed culture cocktails were prepared by blending equal volumes of each strain together.

### *2.2. Sample preparation and inoculation*

Canned tomato paste made of only organic tomatoes was purchased at a local supermarket (Seoul, South Korea) and stored at room temperature kept out of direct sunlight. To prevent spoilage, the canned food was opened right before experiment and transferred to resealable container and stored at 4°C after using. Pasteurized tomato-based salsa, consisting of tomatoes, jalapeño peppers, onions, garlic, and distilled vinegar, was purchased at a local supermarket (Seoul, South Korea) and stored at 4°C. Before experiments, sample was placed at room temperature until 24±1°C was maintained. Tomato paste or salsa (25 g) was inoculated with 0.2 ml of the mixed culture

cocktail (*E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes*) and thoroughly stirred by hand with a spatula for 1 min. The final cell concentration was $10^7$-$10^8$ CFU/ml for *E. coli* O157:H7 and *S.* Typhimurium, and $10^6$-$10^7$ CFU/ml for *L. monocytogenes*.

### *2.3. Experimental apparatus*

The microwave system (Fig. 1) consisted of a high frequency power generator, magnetron head, microwave cavity, waveguide system (Korea Microwave Instrument Co., Gyeonggi-do, South Korea), fiber optic temperature sensors, and signal conditioner (FOT-L, TMI-4; FISO Technologies Inc., Quebec, Canada). The microwave power generator used a 3 phase, 380 V, 60 Hz power supply. The magnetron operated at 915±15 MHz and was rated at 6 kW. The filament of this magnetron was operated at 10 V AC, 35 A. The cavity was made of stainless steel and its dimensions were 871* 500* 850 mm (width* depth* height). An exhaust fan was located at back wall of the cavity. The waveguide size was WR-975. This system

had two modes for operation; power control mode and temperature maintenance mode. Power control mode was used for the current study. The power could be fixed by the power controller and its range was level 0 to 10 corresponding to 0 to 6 kW. The initial preheating time was 30 min for this system. To improve the uniformity of microwave heating, a stirrer and turn-table were included. A stirrer was installed at the geometric center of the wall inside the cavity and the metal blades of the stirrer rotated at 0.80 rpm during treatment. The turn-table motor was operated at 25 W of induction and speed-controlled with a 150:1 gear reduction ratio. Ten liters of water were circulated every min by a cooling system to prevent the magnetron from overheating (>50°C). To measure the temperatures of samples during treatments, fiber optic temperature sensors were inserted through a hole at the top wall of the cavity, and a signal conditioner connected to a personal computer recorded the real-time temperatures at 1 s intervals using FISO Commander 2 Control and Analysis Software.

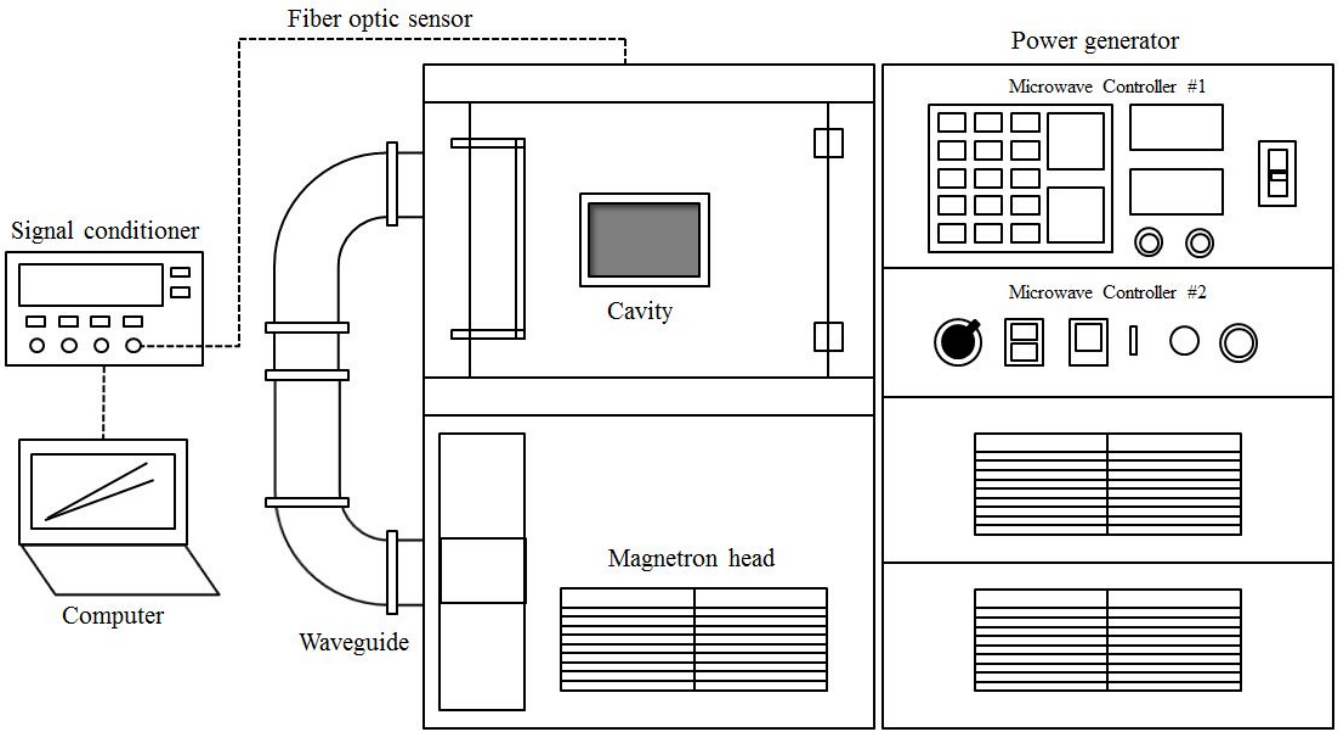



**Fig. 1.** Schematic diagram of a microwave heating system at Seoul National University (Seoul, South Korea)

### *2.4. Microwave heating treatment*

For treatment, 25 g of tomato paste or salsa was dispensed into a microwavable polypropylene container (NALGENE 2118-0008; Thermo Scientific, Hudson, NH). The container was located at the center of the turn-table inside the cavity and subjected to microwave heating. In order to obtain time-temperature profiles, five different power levels, 1.8, 2.1, 2.4, 3.0, and 3.6 kW for tomato paste and 1.2, 1.8, 2.4, 3.6, and 4.8 kW for salsa, were applied until center temperature of tomato paste and salsa reached 90°C and 100°C, respectively. Target temperatures for two samples were determined to maximize the pathogen inactivation effect while maintaining product quality. Fiber optic sensors were used to measure the temperatures of center and side regions of sample-filled containers. For the inactivation study, tomato paste inoculated with pathogens was treated with microwave heating for 210, 110, 85, 55, 40 s at power levels of 1.8, 2.1, 2.4, 3.0, 3.6 kW, respectively, with reference to obtained time-temperature profiles. In the case of salsa, inoculated sample was treated with microwave heating for 110,

60, 50, 40, 30 s at 1.2, 1.8, 2.4, 3.6, 4.8 kW, respectively. And for the quality measurement study, non-inoculated sample was treated with microwave heating for the maximum treatment time at each power level.

### *2.5. Bacteriological analysis*

Twenty-five g treated samples were transferred into sterile stomacher bags (Labplas, Inc., Sainte-Julie, Quebec, Canada) containing 225 ml of sterile 0.2% peptone water and homogenized for 2 min using a stomacher (Easy Mix; AES Chemunex, Rennes, France). After homogenization, 1 ml samples were 10-fold serially diluted with 9 ml of sterile 0.2% peptone water and 0.1 ml of samples were spread-plated onto each selective medium (*E. coli* O157:H7: Sorbitol MacConkey Agar (SMAC), Difco; *S.* Typhimurium: Xylose Lysine Desoxycholate Agar (XLD), Difco; and *L. monocytogenes*: Oxford Agar Base with antimicrobial supplement MB Cell (MOX), MB Cell). All plates were incubated at 37°C for 24 to 48 h before counting colonies characteristic of the pathogens.

### *2.6. Color and pH measurement*

Color was measured by using a Minolta colorimeter (model CR400; Minolta Co., Osaka, Japan). The values for $L^*$, $a^*$, and $b^*$ were recorded to evaluate the color changes of tomato paste and salsa after microwave heating. An untreated sample was used as the control. Before measurement, treated samples were cooled in crushed ice. The parameter $L^*$ is a measure of lightness, $a^*$ is an indicator of redness, and the parameter $b^*$ is a measure of yellowness. The pH was measured with a pH meter (Seven Multi 8603; Mettler Toledo, Greifensee, Switzerland). All measurements were performed in triplicate.

### *2.7. Lycopene measurement*

Lycopene content in tomato product was measured by the method performed by Fish et al. (2002) and Lee et al. (2013). Tomato paste of salsa (0.6 g) was extracted with 20 ml of a mixture of 1:1:2 (v/v) of 95% ethanol; 0.05% w/v butylhydroxytoluene in acetone; and hexane on ice for 15 min. A 50 ml test tube containing sample and mixture was wrapped with aluminum foil to prevent degradation of lycopene due to light. Three ml of distilled water was added and blended by vortex mixer for 1 min. Then, it was left for 5 min to allow separation into two layers. The upper hexane layer was transferred to 1 cm square cuvettes to measure absorbance with a Beckman DU series 68 spectrophotometer (Beckman Instruments, Inc., Fullerton, CA) at 503 nm. Hexane was used as a blank. The concentrations of lycopene in tomato products were determined using absorbance and sample weight with following equation.

$$\text{Lycopene (mg/kg tissue)} = A_{503} * 0.0312/\text{kg sample}$$

### *2.8. Statistical analysis*

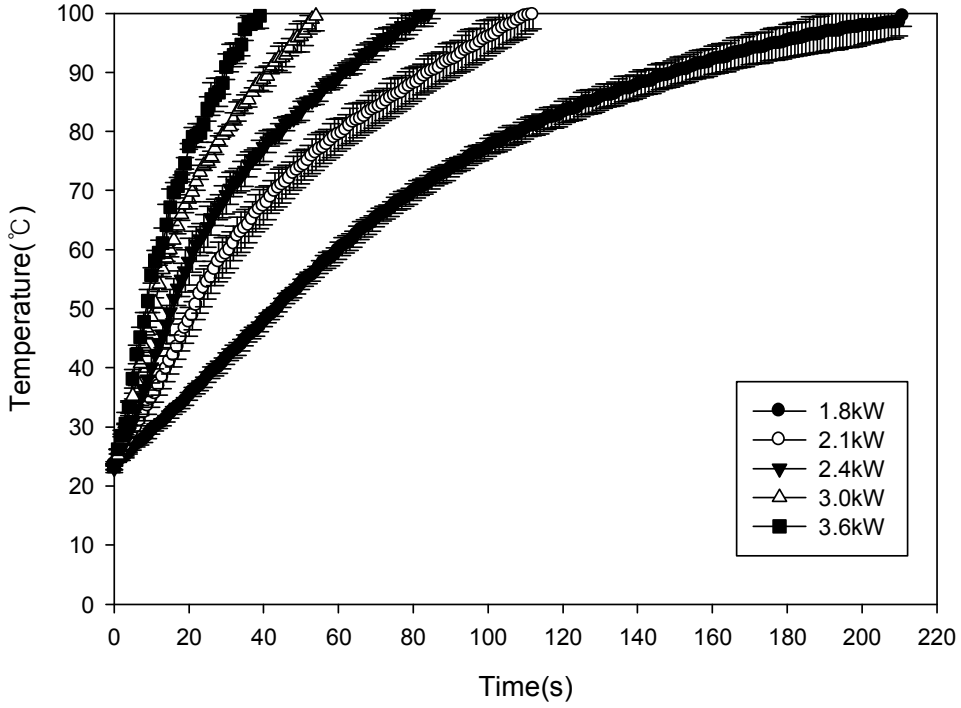
All experiments were duplicate-plated and replicated three times. All data were analyzed with the analysis of variance procedure (ANOVA) of the Statistical Analysis System (SAS Institute, Cary, NC, USA) and Duncan's multiple-range test. Significant differences in mean values during treatments were determined at a significance level of $P = 0.05$.

# III. RESULTS

### *3.1. Time-temperature profiles of tomato paste during microwave heating with different power levels*

The time-temperature profiles of tomato paste during microwave heating treatment at various power levels ranging from 1.8 kW to 3.6 kW are shown in Fig. 2. Fig. 2 (A) and (B) show the center and side temperatures of tomato paste during treatment, respectively. The side temperature was obtained by locating a fiber optic sensor close to the wall of the container which was in contact with the sample. The center temperature of tomato paste increased to 100°C when treated with 1.8 kW for 211 s, 2.1 kW for 112 s, 2.4 kW for 85 s, 3.0 kW for 54 s, and 3.6 kW for 39 s. At these time intervals, the side temperature reached approximately 54°C, 65°C, 64°C, 74°C, and 85°C for 1.8 kW, 2.1 kW, 2.4 kW, 3.0 kW, and 3.6 kW, respectively.

A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Time(s)
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2.4kW
3.0kW
3.6kW

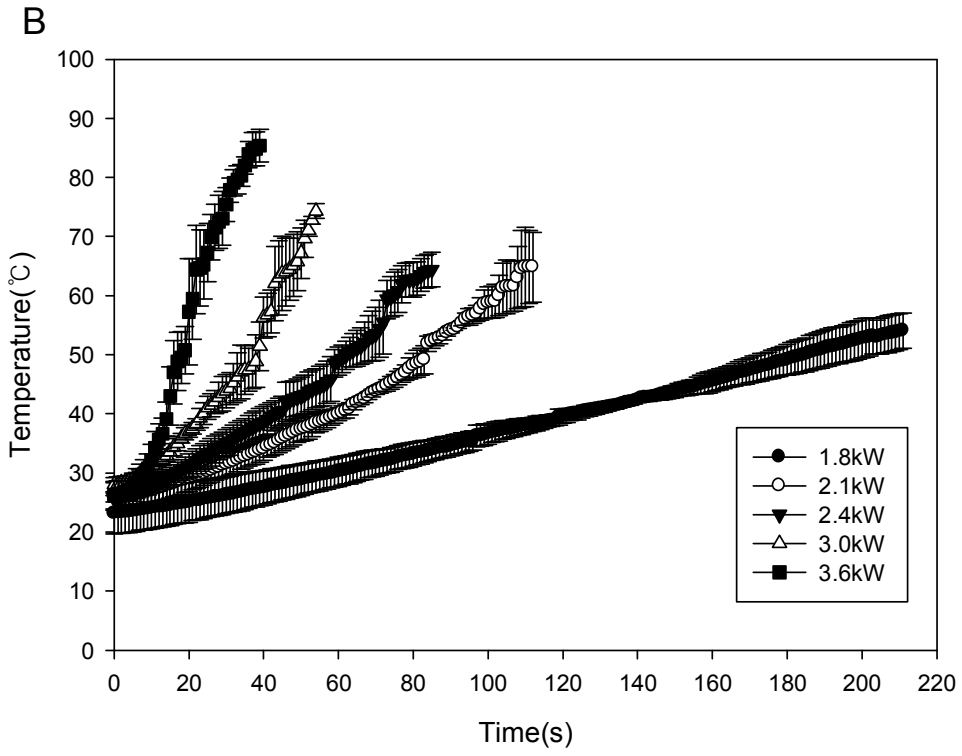
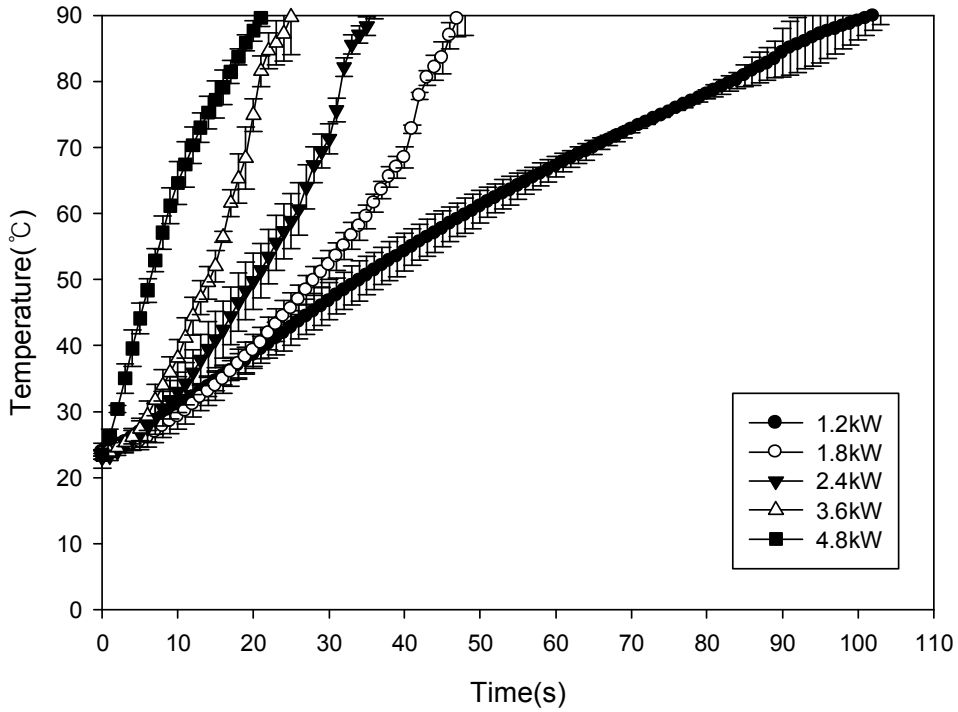



**Fig. 2.** Time-temperature profiles of center (A) and side portion (B) of tomato paste during microwave heating with different power levels. The results are means from three experiments, and error bars indicate standard deviations.

### *3.2. Time-temperature profiles of salsa during microwave heating with different power levels*

Average temperatures of salsa during microwave heating treatment at various power levels ranging from 1.2 kW to 4.8 kW are shown in Fig. 3. As shown in Fig. 3 (A), the center temperature of salsa increased to 90°C when treated with 1.2 kW for 104 s, 1.8 kW for 49 s, 2.4 kW for 37 s, 3.6 kW for 26 s, and 4.8 kW for 22 s. Fig. 3 (B) shows the side temperatures of salsa during same treatment time. The temperature of side portion achieved 67°C, 60°C, 65°C, 73°C, and 81°C for 1.2 kW, 1.8 kW, 2.4 kW, 3.6 kW, and 4.8 kW, respectively.

A


Temperature(℃)
Time(s)
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1.2kW
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2.4kW
3.6kW
4.8kW

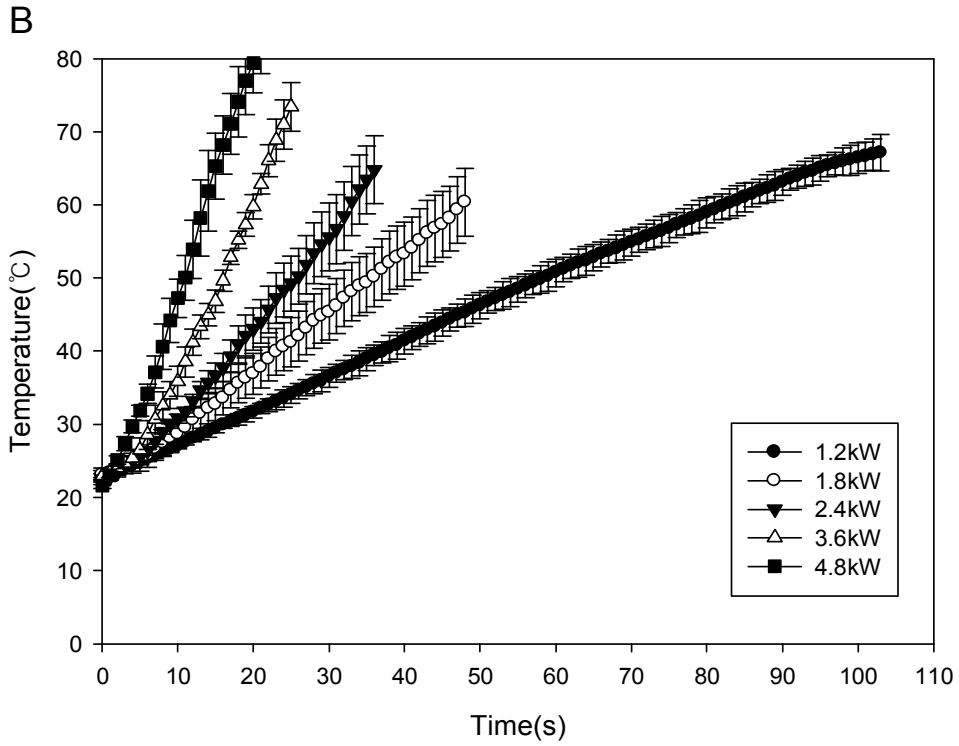



**Fig. 3.** Time-temperature profiles of center (A) and side portion (B) of salsa during microwave heating with different power levels. The results are means from three experiments, and error bars indicate standard deviations.

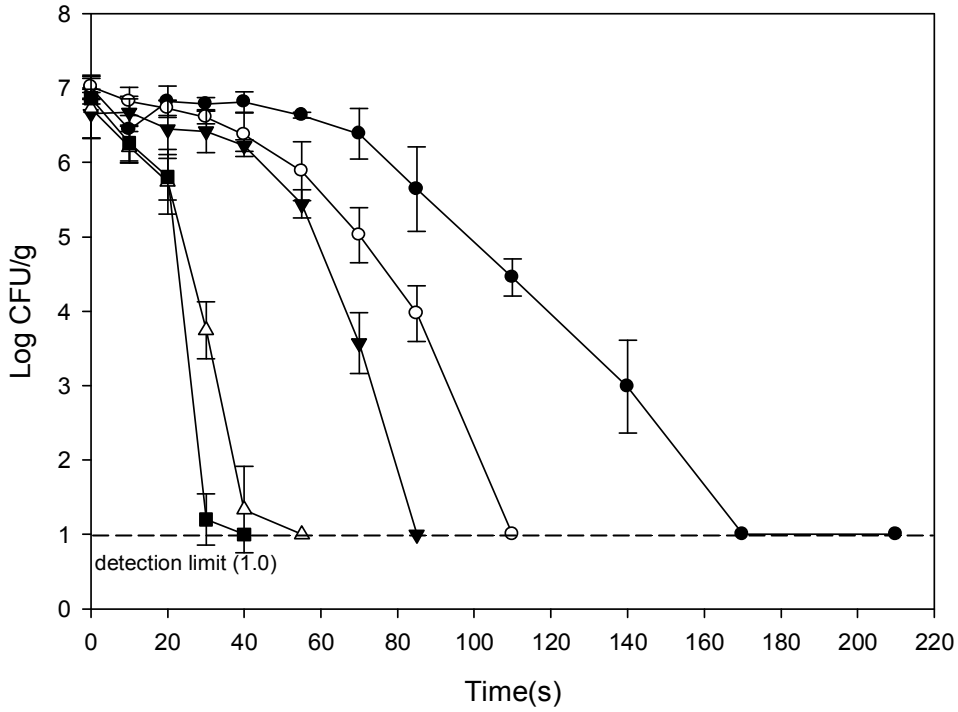
### *3.3. Effect of microwave heating with different power levels on inactivation of foodborne pathogens in tomato paste and salsa*

The levels of surviving cells of the three pathogens in tomato paste and salsa after microwave heating treatment are shown in Fig. 4 and 5, respectively. The populations of all pathogens were reduced to below the detection limit (1.0 log CFU/g) after treatment at all power levels with maximum treatment time in tomato paste as shown in Fig. 4. Log reduction of *E. coli* O157:H7, *S.* Typhimurium and *L. monocytogenes* were ranged from 5.66 to 6.02 log CFU/g, from 5.83 to 6.10 log CFU/g and from 4.64 to 4.93 log CFU/g, respectively, and there was no significant difference in reduction population depending on treatment power level in three pathogens. In the case of 1.8 kW, population reductions below detection limit were also found after treatment for only 170 s.

Fig. 5 (A) shows the inactivation effect of microwave heating against *E. coli* O157:H7 in salsa. Populations were reduced by 5.86, 5.17, and 5.47 log CFU/g after treatment at 1.2, 1.8, and 2.4 kW, respectively. In the case of

both 3.6 and 4.8 kW treatment, counts of *E. coli* O157:H7 were reduced to below the detection limit. The inactivation of *S.* Typhimurium in salsa is shown in Fig. 5 (B), and the trend of reduction was similar to that of *E. coli* O157:H7. Populations of the pathogen after microwave heating at 1.2, 1.8, 2.4, and 4.8 kW were reduced by 5.94, 5.69, 5.76, and 5.83 log CFU/g, respectively. The 3.6 kW treatment reduced *S.* Typhimurium to below the detection limit. Fig. 5 (C) shows the bactericidal effect of microwave heating against *L. monocytogenes.* The reduction trend did not differ from those of *E. coli* O157:H7 and *S.* Typhimurium. Populations of *L. monocytogenes* were reduced by 4.73 and 4.58 log CFU/g at 1.2 and 1.8 kW, respectively, and were lowered to below 1.0 log CFU/g at 2.4, 3.6, and 4.8 kW.

A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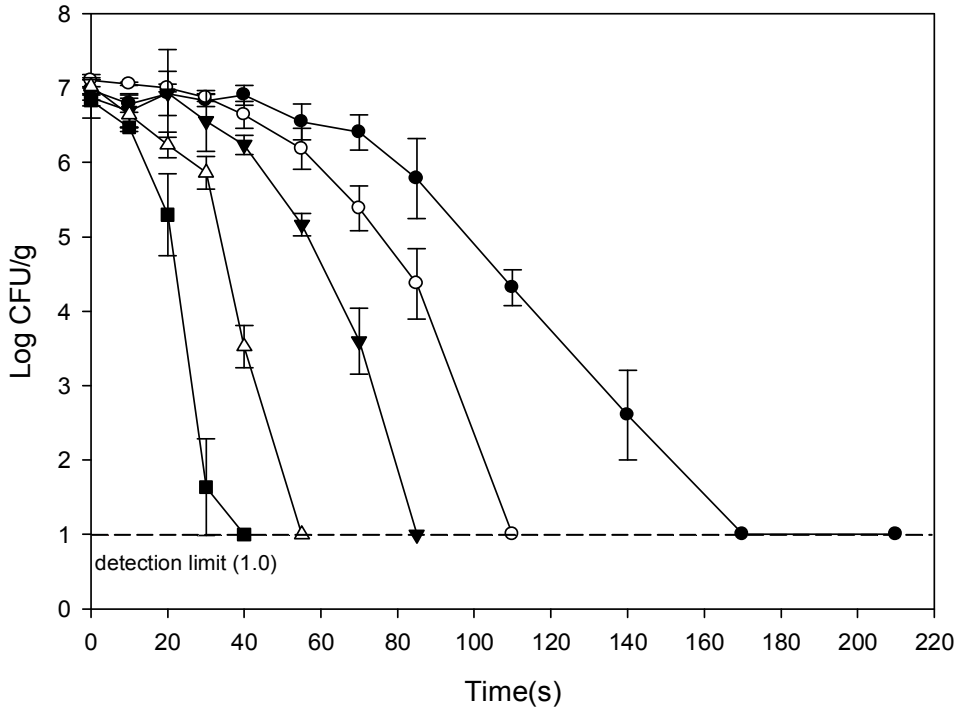
B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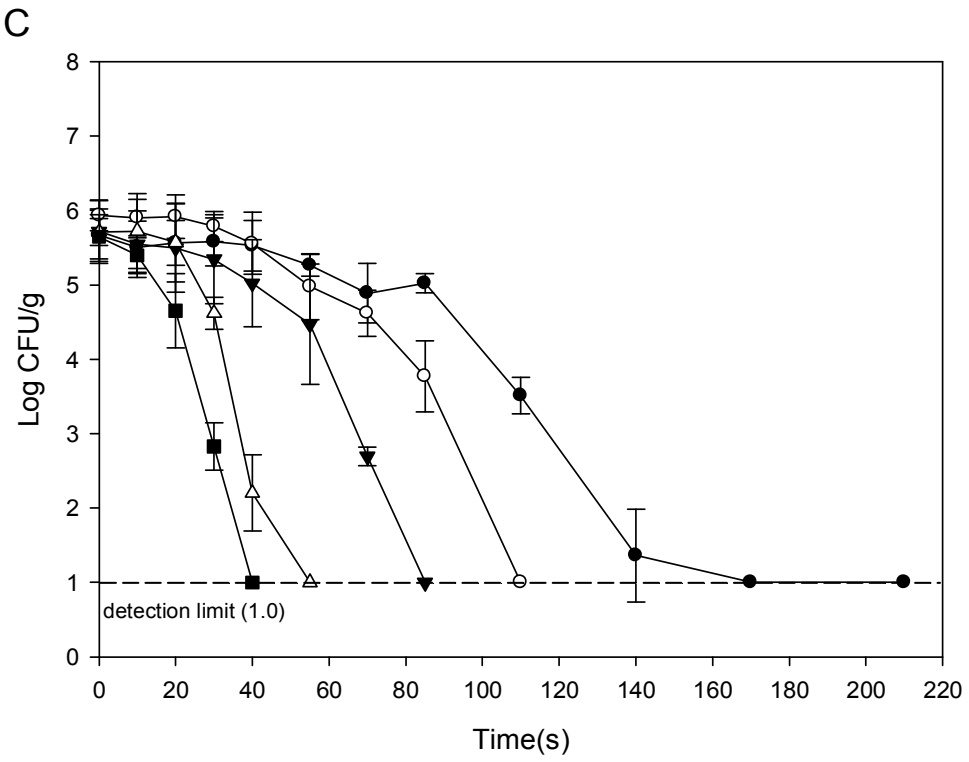
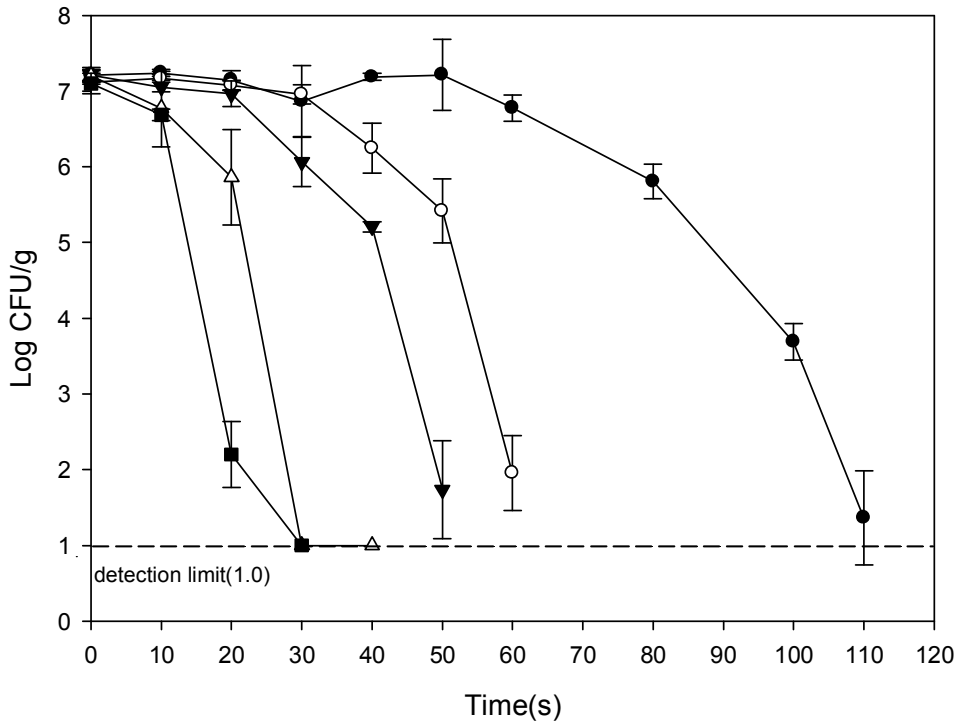



**Fig. 4.** Survival curves for *Escherichia coli* O157:H7 (A), *Salmonella* Typhimurium (B) and *Listeria monocytogenes* (C) in tomato paste treated with microwave heating at power levels of 1.8 kW (●), 2.1 kW (○), 2.4 kW (▼), 3.0 kW (△), 3.6 kW (■). The results are means from three experiments, and error bars indicate standard deviations

A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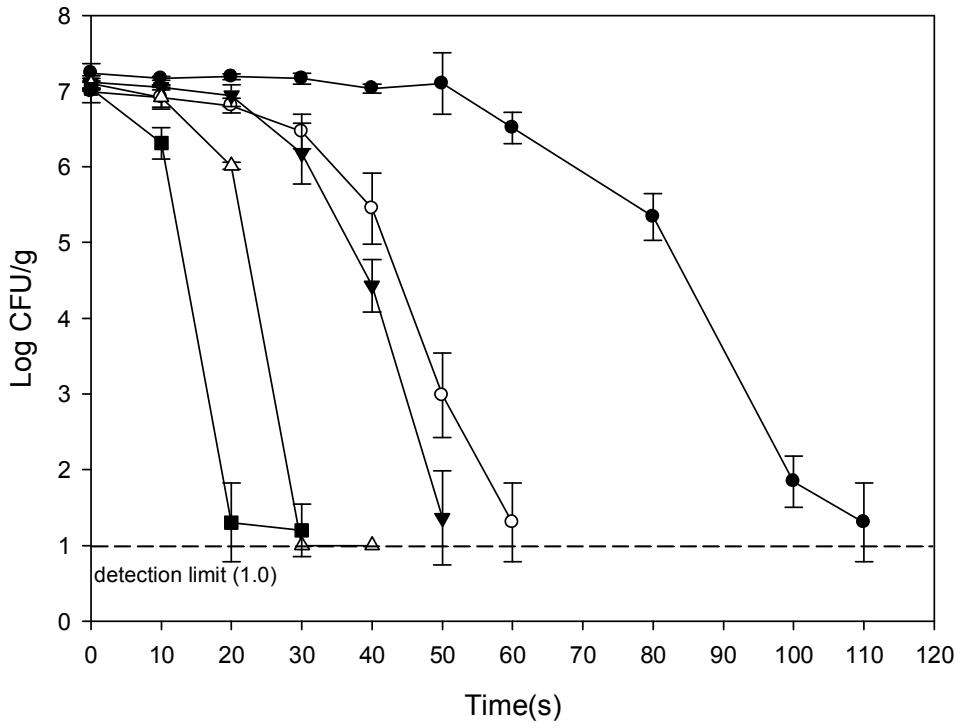
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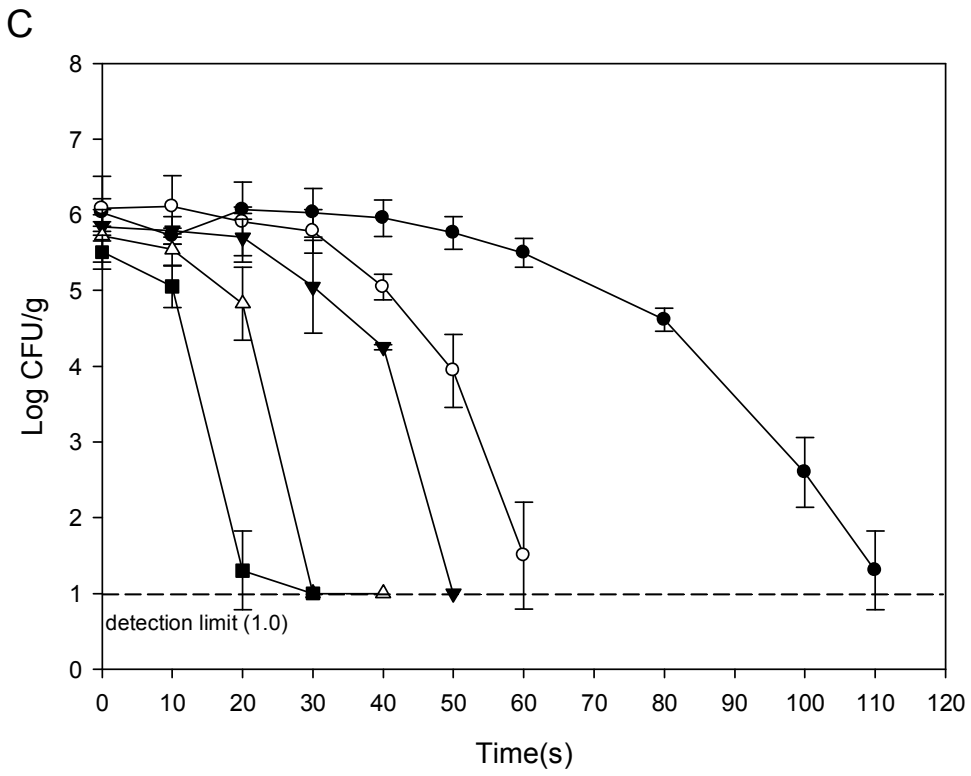


**Fig. 5.** Survival curves for *Escherichia coli* O157:H7 (A), *Salmonella* Typhimurium (B) and *Listeria monocytogenes* (C) in salsa treated with microwave heating at power levels of 1.2 kW (●), 1.8 kW (○), 2.4 kW (▼), 3.6 kW (△), 4.8 kW (■). The results are means from three experiments, and error bars indicate standard deviations.

### *3.4. Influence of microwave heating with different power levels on product quality*

The color values, pH, and lycopene content of tomato paste and salsa after microwave heating at different power levels are shown in Table 1 and 2, respectively. $L^*$, $a^*$ and $b^*$ values of tomato paste samples were ranged from 31.06±0.11 to 31.73±0.07, from 26.32±0.27 to 26.97±0.31 and from 26.57±0.28 to 26.99±0.22, respectively. There was significant difference in $L^*$ value between untreated and treated tomato paste, but the difference was not large. Microwave heating did not affect $a^*$, $b^*$ values, pH, and lycopene content of tomato paste. The lycopene content in tomato paste treated with microwave heating ranged from 23.75±1.58 to 24.60±2.53 mg/kg and that of untreated sample was 24.60±3.98 mg/kg.

$L^*$, $a^*$, $b^*$ values and pH of all treated salsa samples were not significantly different ($P>0.05$) from those of the control. In the case of lycopene content, there was no significant difference between untreated and treated salsa except for samples treated with 4.8 kW which yielded 67.72±1.65 mg/kg of

lycopene. The lycopene content was 75.47 mg/kg for the control and ranged from 74.46±1.42 to 75.82±3.39 mg/kg after microwave heating at power levels of 1.2, 1.8, 2.4, and 3.6 kW.

**Table 1.** Color values, pH, and lycopene content of microwave heated and untreated tomato paste[a]

| Power (kW) | Parameter[a] | | | pH | Lycopene (mg/kg) |
|---|---|---|---|---|---|
| | $L^*$ | $a^*$ | $b^*$ | | |
| 0 | 31.73±0.07A | 26.81±0.41A | 26.71±1.26A | 3.87±0.17A | 24.60±3.98A |
| 1.8 | 31.29±0.09B | 26.97±0.31A | 26.57±0.28A | 3.86±0.15A | 24.58±1.41A |
| 2.1 | 31.06±0.11B | 26.65±0.53A | 26.99±0.22A | 3.86±0.15A | 23.92±3.97A |
| 2.4 | 31.07±0.20B | 26.32±0.27A | 26.77±0.07A | 3.92±0.16A | 23.78±2.59A |
| 3.0 | 31.25±0.31B | 26.64±0.59A | 26.96±0.36A | 3.84±0.17A | 23.75±1.58A |
| 3.6 | 31.30±0.08B | 26.81±0.33A | 26.81±0.58A | 3.88±0.15A | 24.60±2.53A |

[a] Means ± standard deviation. Values followed by the same letters within the column are not significantly different ($P > 0.05$).

[b] Color of parameters are $L^*$ (lightness), $a^*$ (redness), $b^*$ (yellowness).

**Table 2.** Color values, pH, and lycopene content of microwave heated and untreated salsa

| Power (kW) | Parameter[a] | | | pH | Lycopene (mg/kg) |
|---|---|---|---|---|---|
| | $L^*$ | $a^*$ | $b^*$ | | |
| 0 | 33.06±1.43A | 9.42±0.62A | 14.86±1.28A | 3.86±0.01A | 75.47±0.53A |
| 1.2 | 32.94±0.58A | 8.76±0.41A | 13.63±0.56A | 3.85±0.01A | 74.80±0.08A |
| 1.8 | 33.19±1.33A | 9.22±0.20A | 14.37±0.11A | 3.85±0.01A | 75.82±3.39A |
| 2.4 | 32.02±0.84A | 9.50±0.16A | 14.38±0.53A | 3.85±0.01A | 74.48±3.00A |
| 3.6 | 32.50±0.68A | 9.27±0.79A | 13.91±1.12A | 3.85±0.01A | 74.46±1.42A |
| 4.8 | 32.03±0.68A | 8.87±0.47A | 14.26±1.16A | 3.85±0.02A | 67.72±1.65B |

[a] Means ± standard deviation. Values followed by the same letters within the column are not significantly different ($P > 0.05$).

[b] Color of parameters are $L^*$ (lightness), $a^*$ (redness), $b^*$ (yellowness).

# IV. DISCUSSION

The objectives of this study were to investigate the effect of microwave heating with different power levels on heating appearance, inactivation of foodborne pathogens, and quality of tomato products. We confirmed that the center temperature of sample increased as treatment time increased at designated power levels. Also, the time which is necessary to reach specific temperatures decreased as power level increased. Microbial analysis based on time-temperature profiles was conducted and effective reductions of three pathogens in both tomato paste and salsa were achieved after microwave heating. At the same time, no significant quality changes occurred in general.

As shown in Fig. 2 (A) and Fig. 3 (A), as treatment power increased from 1.8 to 3.6 kW and from 1.2 to 4.8 kW, the time needed for the center portion to reach target temperature (100°C and 90°C) decreased. We confirmed that when a higher level of power was applied to tomato products, a relatively shorter time was needed to heat the sample to a specific temperature. Fig. 2

and Fig. 3 indicate that the temperature of the sample center portion was always found to be higher than that of side portion at the same time intervals during treatment and the final temperature difference between center and side decreased as microwave treatment power level increased except for 1.2 kW treatment of salsa. It was reported that heating of surface or center portions was greatly affected by frequency in microwave heating. In the case of microwave treatment operating at a frequency of 915 MHz, the geometric center reached a higher temperature than the surface of the sample which was in contrast to 2,450 MHz which showed a surface heating effect (Mudgett, 1989).

However, it is difficult to assert that the temperature difference observed in results of the present study was only due to the above theory, because there are many critical factors that may affect temperature distribution during microwave heating. For instance, there are variable characteristics of foods such as shape, volume, composition, and dielectric properties and features of processing equipment like frequency, power, and geometry (Datta and Davidson, 2000; Gerbo et al., 2008). Actually, non-uniform heating is a main

problem of microwave heating and there have been some studies that explored temperature distribution in different kinds of foods during treatment. Coronel et al. (2003) treated milk with a continuous-flow tubular microwave system at 915 MHz and 5 kW. They reported that temperatures in the cross-sectional area of the tube at the end of the applicator were quite uniform with especially the central part being hottest. Kumar et al. (2007) found that temperature difference between the center and wall of the tube decreased as the outlet temperature increased during treatment of *salsa con queso* (salsa with cheese) by a continuous-flow microwave system at 915 MHz and power output of 3 kW. Those authors postulated that because *salsa con queso* absorbed relatively uniform energy at a higher temperature, those sample temperature distributions were obtained.

The population of surviving pathogens showed a decreasing tendency in all samples when treatment time increased at a given power level. As power level of the microwave system increased, times needed to satisfy a minimum 5 log reduction for *E. coli* O157:H7 and *S.* Typhimurium, and a 4 log reduction for *L. monocytogenes* became shorter. There are some studies that

correlate with the results of our study. Cañumir et al. (2002) reported that reductions of *E. coli* populations ranging from 2 to 4 log CFU/ml were obtained in apple juice depending on the microwave power level and treatment time (720 W for 90 s and 900 W for 60 s). Also, they confirmed that D-value decreased as power level increased (3.88±0.26 min for 270 W and 0.42±0.03 min for 900 W). Although Lu et al. (2011) suggested using a microwave system at medium power (700 W) for 40 s to obtain a greater than 1.45 log reduction of *Salmonella enterica* on grape tomatoes without changing texture quality, bactericidal effect was greater at a high power level than at a medium power level.

Color is a very vital factor for quality evaluation of tomato products (Barreiro et al., 1997). In the case of conventional heating which for many foods requires about 4 times longer time intervals than microwave heating, it is difficult to avoid thermal degradation of existing nutrients and changes in quality parameters (Suárez et al., 2000). Picouet et al. (2009) reported that there were significant changes in $L^*$ and $a^*$ values and smaller changes for $b^*$ values when apple puree was preserved using microwave heating. Vega-

Miranda et al. (2012) showed that water-assisted microwave heating had an effect on the color of vegetables, especially darkening. However, Lu et al. (2011) found no significant changes in any color parameters after microwave heating treatments of grape tomatoes. Also there were no significant differences in pH value and lycopene content between control and treated samples.

In the present study, several quality parameters were analyzed after microwave heating treatment. Similarly, we confirmed that microwave heating did not affect $L^*$, $a^*$, $b^*$ values, pH, and lycopene content of tomato paste and salsa in principle. Datta and Davidson (2000) and Cañumir et al. (2002) mentioned that short come-up time is one advantage of microwave heating and this allows foods to preserve their natural characteristics. Nevertheless, many studies reported an adverse effect of thermal treatment, including microwaving, on carotenoid content in tomato products which actually can occur during production processing in a factory (Abushita et al., 2000; Takeoka et al., 2001). In the current study, although microwave heating treatment did not have a significant effect on lycopene content of

tomato paste, there was a small difference in lycopene content of salsa between control and sample when treated with 4.8 kW. When both pathogen inactivation and maintaining product quality were carefully considered, 4.8 kW might not be the most desirable power level for processing salsa. Even if 4.8 kW was adequate for effectively inactivating pathogens within the designated time, it had a detrimental effect on one of the quality parameters. Nevertheless, we estimate that it was a high enough power level to produce a relatively uniform energy distribution compared to other power levels at treatment times needed for the center portion of the sample to reach 90°C.

In conclusion, the results of this study illustrate the great effectiveness of 915 MHz microwave heating for inactivating *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes* in tomato products without significantly impacting quality for almost every treatment combination. Further, this study has very important significance in that this is one of first studies investigating the inactivation effect of microwave heating at 915 MHz against pathogens present in foods. Therefore, this study provides fundamental data needed for application of 915 MHz microwave systems for

processing various foods. Furthermore, microwave heating can be applied to production processing of tomato based products to ensure superior microbiological safety. However, it should be considered that many factors may be of importance which can vary with every study and can affect the microwave heating pattern in many kinds of foods. For better application of microwave heating to food processing, the effect of each factor of influence on microwave heating must be studied in the future.

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# VI. 국문초록

마이크로파가열은 식품가공을 위한 대표적인 열처리 기술 중 하나로서 기존 열처리 방법과 달리 식품에 진동하는 전기장을 형성시키고, 이에 따른 쌍극성 및 이온성 물질의 작용을 통해 식품 내부에서부터 열을 발생시키는 기술이다. 따라서 비교적 품질 변화가 적으므로 효율적인 식품 가공처리가 가능하다. 그러나 현재까지 식품 내 병원성 균에 대한 915 MHz 마이크로파 시스템의 살균 효과를 보고한 연구는 매우 부족한 실정이다. 이에 본 연구에서는 토마토 제품인 토마토 페이스트와 살사에서 *E. coli* O157:H7, *S.* Typhimurium 및 *L. monocytogenes* 에 대한 915 MHz 마이크로파 시스템의 저감화 효과를 조사하였다. 또한 마이크로파 가열 처리를 한 후, 토마토 제품의 색, pH 및 리코펜 함량 변화를 연구하였다. 915 MHz 마이크로파 시스템을 적용하는데 있어

최적의 전력 수준-시간 처리 조건을 탐색하기 위해 세 종류의 병원균을 접종한 토마토 페이스트 (1.8, 2.1, 2.4, 3.0, 3.6 kW)와 살사(1.2, 1.8, 2.4, 3.6, 4.8 kW)에 전력 수준별로 각각 마이크로파 가열 처리를 하였다. 토마토 페이스트와 살사의 중심부 온도가 각각 90 도와 100 도에 도달할 때까지 시간에 따른 온도 상승 변화를 측정한 결과, 처리하는 전력 수준이 높아질수록 시료의 중심부가 목표 온도에 도달하는데 소요되는 시간이 감소하는 것을 확인하였다. 처리 중 중심부와 주변부의 온도 간에 차이가 발생하였으나, 이는 정해진 전력 수준 중 높은 전력을 처리할수록 감소하는 경향을 보였다. 특정 전력 수준에서 처리 시간이 증가함에 따라 병원균이 감소하였고, 높은 전력을 처리한 경우 상대적으로 짧은 시간 내에 특정 수준의 병원균을 효과적으로 저감할 수 있었다. 토마토 페이스트의 경우 마이크로파 가열 처리 후 세 종류의 병원균 모두 검출 한계 (1.0 log CFU/g) 이하로 저감화되었고, 살사에서는 *E. coli* O157:H7, *S.* Typhimurium, *L.*

*monocytogenes* 각각 5.17-6.21 log CFU/g, 5.76-6.10 log CFU/g, 4.51-4.84 log CFU/g 수준의 저감화가 일어났다. 마이크로파 가열처리 후 시료의 색, pH, 리코펜 함량의 변화는 대체로 유의적인 차이를 나타내지 않았다. 이러한 결과는 토마토 페이스트와 살사에 대한 915 MHz 마이크로파 가열처리는 식품의 미생물학적 안전성을 향상시킴과 동시에 품질을 보존할 수 있다는 점에서 기존 살균 과정을 대체할 수 있는 기술임을 나타낸다.

주요어: 마이크로파 가열, 915 MHz 마이크로파 시스템, 식중독 균, 토마토 제품

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