Post-Processing Temperature Rise in Foods: Conventional Hot Air and Microwave Ovens

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(Received for publication October 1, 1984)

ABSTRACT

Measurement of temperature rise (N = 5 replications) in water (1000 ml), chicken frankfurters (46 ± 2 g/frankfurter) and cake cones (40 g/cone) after conventional hot air (160°C) and after microwave (2450 MHz; 50% and 100% power of 645 ± 25 W) processing indicated that temperature rise occurred more often in products heat-processed in microwave than in hot air ovens. Duration and extent of post-processing temperature rise (PPTR) in beef loaf patties (150 g/patty), pork and turkey roasts (approximately 2.3 kg/roast) and turkey casserole (0.9 kg/casserole) prepared in microwave ovens was quantified during three replications. Although present, PPTR should not change temperature objectives for domestic microwave processing of foods because of the extensive variability of duration and extent in PPTR within and among experimental products tested. However, PPTR should be given consideration when commercial products to be processed in microwave ovens and those used in mathematical modeling of microwave cooking/heating procedures are designed.

Minimum temperature objectives for food safety frequently surpass maximum temperature objectives for optimization of nutritional and sensory qualities of food. Thus, to conserve nutritional and sensory qualities of food and still retain microbiological safety of the food, temperature objectives for processing of food by heat are often narrow in range. For example, to insure, microbiological safety of a meat product such as beef loaf, the beef loaf should be heat-processed to a minimum temperature of 74°C (12). To conserve nutritional and sensory qualities of the beef loaf, maximum internal end-point-temperature (EPT) of the loaf should be ≤ 77°C (1). Recently, the minimum temperature objective for microbiologically safe pork was recommended to be raised from 65 to 77°C because Trichinella spiralis survived in pork samples partially processed by microwave energy to EPT's ≤ 65°C (13). Maximum temperature objective for processing fresh pork has been given as 79.5°C (4). Increased losses in sensory quality, moisture and nutritional quality, particularly B-vitamins, are likely when the EPT is raised (7).

The suggestion has been made that post-processing temperature rise (PPTR) be added to EPT when minimum temperature objectives are considered (5). Such recommendations are being made when information in the literature on extent of PPTR is extremely limited for either hot air or microwave processing techniques.

Information is needed about the extent of PPTR to standardize processing times so that food safety may be assured with minimum losses of nutritional and sensory qualities. Thus, purposes of this study were to: (a) compare the extent of PPTR in foods and yield of those products processed by hot air and by microwave energy, and (b) document the extent and duration of PPTR in selected common meat entrees processed in a microwave oven.

METHOD

The period of temperature rise after processing was termed "dwell time" by Kotula (5) and "standing time" by Zimmerman and Beach (13). For purposes of this study, the term "dwell time" was chosen and more specifically defined as that period following microwave processing during which product temperature continues to rise at that site in the product where the lowest temperature was found. Lowest temperatures were assumed to be found at approximate geometrical centers of experimental products.

For Phase I of the study (to compare relative PPTR after hot air and microwave processing), three experimental products were heat-processed in microwave and conventional hot air ovens. Product temperatures were monitored continuously during and after processing. The experiment was replicated five times.

For phase II of the study (to document extent and duration of PPTR of selected, common meat entrees processed by microwave energy), four additional experimental products were processed in one of two randomly selected microwave ovens. Product temperatures were monitored in up to 16 locations per product during and after processing in three replications of the experiment.

Phase 1. Relative PPTR: hot air and microwave ovens

To determine the effect of heat source on post-processing temperature rise, PPTRs of foods processed in microwave ovens were compared to PPTRs in foods processed in conventional hot air ovens. The effect of wattage output (50 and 100% of 643 ± 25 W) during microwave processing on PPTR rise was...
also chosen for observation since reduced wattage has recently been recommended for increased food safety when cooking pork (5).

Ovens. One of three microwave ovens (Model No. 56-4887-10, Tappan Appliance Group, Mansfield, OH; Model No. RR-8A, Amana Refrigeration, Amana, IA; Model No. 419, Litton Systems Inc., Minneapolis, MN) was randomly chosen for processing of each product to avoid possible effect of energy distribution pattern on temperature. Wattage outputs of microwave ovens were calculated using 1000 ml of water heated 120 s according to the method recommended by Copson (2). Experimental products were also processed in a hot air oven (DWG, Model No. 521B32P1, General Electric Co., Appliance Park, Louisville, KY) set at 160°C, a commonly used setting for processing of each product to avoid possible effect of energy distribution pattern on temperature. Wattage outputs of microwave ovens were calculated using 1000 ml of water heated 120 s according to the method recommended by Copson (2). Experimental products were also processed in a hot air oven (DWG, Model No. 521B32P1, General Electric Co., Appliance Park, Louisville, KY) set at 160°C, a commonly used setting for baking cakes or roasting meat products.

Experimental products. Experimental products were chosen based on their homogeneous character. Other factors involved in product choice were ability to be processed (cooked or re-heated) in microwave or hot air ovens and extent of current usage in foodservice and domestic markets.

Distilled water (1000 g), one of three experimental products, was weighed into a 190 x 100 cm pyrex crystallizing dish. Water, covered with plastic wrap, (Saran Wrap™, Dow Chemical, U.S.A., Midland, MI) was held overnight at 5°C to: (a) obtain a uniform temperature, and (b) simulate safe food handling practices for hazardous foods. Water was heated 120 s to 18.3 ± 2.0°C in the microwave oven to determine wattage output and to a similar temperature in the hot air oven (5 min).

For the second experimental product, one chicken frankfurter (44 to 48 g; 2-4°C) was placed in the center of a pyrex crystallizing dish and heated to the temperature objective of 74°C. Temperature at the center of the chicken frankfurter was monitored continuously during and after heat processing to determine duration and extent of post-heat temperature rise during dwell time.

For the third experimental product, cake mix (9 oz. package, Jiffy White Cake Mix, Chelsea Milling Co., Chelsea, MI) was reconstituted according to package directions. Enough cake mix was added to an ice cream cone (Stock No. 210, Eat-It-AU with Carnival Cone, Maryland Cup Corporation, Owings Mill, MD) to equal 40 g as weighed on an electronic balance (Model D-1000 Mettler Instrument Co., Hightstown, N.J.). Single cake cones were processed until done according to package directions (conventional oven, 30 min; microwave oven, 40 s/100% power, and 80 s/50% power).

Temperatures of experimental products during and after heat processing were obtained from the approximate geometric center of the food. Temperatures of foods processed in a microwave oven were monitored using a fluoroptic thermometer (Model 1000A, Digital Readout Device and Model GSA-4-10082 probe, Luxtron, Mountain View, CA). Temperatures of foods processed in the conventional oven were monitored using a recording potentiometer and iron-constantan thermocouples (Model 95456, Honeywell, Ft. Washington, PA). Luxtron and Honeywell temperature recording equipment was simultaneously calibrated to give correct readings in ice water and boiling water.

To determine yield, duplicate samples of experimental products were weighed before and after heat-processing using an electronic balance (Type P-1000 Mettler Instrument Co., Hightstown, N.J.). Percent yield was calculated by dividing weight after processing by weight before processing and multiplying the product by 100.

Part II. PPTR of common meat entrees: a microwave oven

Experimental products (beef loaf patties, pork and turkey roasts, and turkey casserole) were microwave-processed in one of two randomly selected microwave ovens (Model RRL-3TA, Amana Refrigerator, Inc., Amana, IA; Model No. 56-4887-10, Tappan Appliance Group, Mansfield, OH), according to directions in a microwave cookbook (6).

To determine time of microwave processing, approximate center internal temperatures of experimental products were monitored during and after microwave heating using a Luxtron Fluoroptic Thermometer and fiber optic probe. Left and right side post-heat temperatures of turkey and pork roasts post-heat were monitored using two Wahl platinum probes (Platinum Resistance Probe P/N 202; Digital Heat Prober Model #350XC, Wahl Instruments, Culver City, CA); 16 iron-constantan probes attached to a Honeywell potentiometer measured post-heat temperature at 16 locations in beef loaf patties. Center internal end-temperature objectives were determined according to microbiological guidelines for safe food handling practices (6) and cookbook instructions (3).

Beef loaf patties (150-g initial raw weight: 86% by weight of ground beef which was 10% fat, 7.0% dehydrated minced onions, 6.0% oatmeal, 0.8% salt and 0.2% nutmeg) were microwave-processed in a donut-shaped pyrex crystallizing dish (12.5 x 6.5 cm; 1.2 cm stem) for 90 s. Boneless, tied raw pork loin roasts, obtained from a local meat cutter, and boneless, ready to serve turkey roll, (white and dark meat; Code 10502, Bil-mar Foods, Inc., Zealand, MI) were placed individually on a 29.8 x 19.1-cm pyrex baking dish on top of a 24.1 x 19.1 x 1.2-cm disposable cardboard roasting rack (EZ Por Corp., Wheeling, IL) and microwave-processed according to directions in Table 1. To decrease effect of possible hot spots, roasts were rotated horizontally 180 degrees every 20 min.

The turkey casserole, composed of 26.3% cooked egg noodles by weight, (16 oz. package, Mueller Old Fashioned Egg Noodles, Enriched, D. F. Mueller, Co., Jersey City, N.J.), 41.3% reconstituted mushroom soup (0.23 kg potable tap water, 1.4 kg/can of soup, Cream of Mushroom Soup, Campbell Soup Co., Camden, N.J.) and 32.5% of approximately 2.5-cm square pieces of ready-to-serve turkey (boneless, white and dark rolled), was microwave-processed in a 10.0 x 19.0-cm pyrex crystallizing dish. The fiber optic temperature probe was held at the approximate center of the food mass by a glass tubing guide and was inserted into a piece of the turkey meat.

RESULTS

Phase I: Relative PPTR: hot air and microwave ovens

Temperature and yield. Figures 1 and 2 are graphs of temperature patterns of water, chicken frankfurters and cake cones processed in a microwave or in a hot air oven. EPT, time of processing and yield of experimental products processed in hot air and microwave ovens are listed in Table 2.

Keeping time constant, temperature objectives for chicken frankfurters (74-77°C); (12) were achieved when mean temperature was considered. However, standard deviations as large as 12.4°C suggested that some batches would not be "microbiologically safe" on the basis of EPT. Similar conclusions have also been reported by Ridley and Matthews (8) and by Sawyer et al. (10). Yield of products was similar between hot air- and microwave-
TABLE 1. Cook/heating parameters of meat entrees used to determine post-processing temperature rise.

<table>
<thead>
<tr>
<th>Product and weight</th>
<th>Beginning temperature (°C)</th>
<th>End temperature(^b)</th>
<th>Microwave processing parameters (W/min)</th>
<th>Yield (%)</th>
<th>Size before processing (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef loaf pattie, 150 g</td>
<td>10 ± 4</td>
<td>103 ± 2</td>
<td>712 ± 0 W/90 ± 0 s</td>
<td>92.8 ± 0.0</td>
<td>12.5 diameter × 1.5 high</td>
</tr>
<tr>
<td>Pork roast</td>
<td>3 ± 1</td>
<td>77 ± 0</td>
<td>691 ± 39 W/14 ± 0 min and 223 ± 39 W/70 ± 0 min</td>
<td>71.7 ± 3.5</td>
<td>27.9 long × 11.4 diameter</td>
</tr>
<tr>
<td>Turkey roast</td>
<td>2 ± 0</td>
<td>74 ± 0</td>
<td>312 ± 55 W/92 ± 5 min</td>
<td>78.0 ± 0.7</td>
<td>22.9 long × 8.8 diameter</td>
</tr>
<tr>
<td>Turkey casserole, 0.9 ± 0 kg</td>
<td>4 ± 2</td>
<td>74 ± 0</td>
<td>690 ± 39 W/11 ± 0 min</td>
<td>88.0 ± 3.5</td>
<td>17.7 diameter × 4.4 high</td>
</tr>
</tbody>
</table>

\(^{a}\)N = 3 replications.

\(^{b}\)Internal end temperature reading required on the Luxtron fiber optic probe to achieve temperature objectives ≥74°C on the iron constant thermocouples during dwell time.

\(^{c}\)Probe in a 2.5-cm cube of turkey meat.

processing except that yield of cake cones microwaved at the 50% power level was 3% higher than yield of cake cones processed at the 100% power level.

Effect of microwave power level on time-temperature pattern. As expected, products processed at the 100% power level reached temperature objectives sooner than did products processed at the 50% power level (Fig. 1). The lower the power level, the flatter the microwave heating curve tended to appear.

Post-processing temperature rise. Duration of dwell time and extent of PPTR during dwell time for products heated in microwave ovens are summarized in Table 2. Experimental products processed in the hot air oven did not exhibit post-heat temperature rise. Thus PPTR may be more commonly associated with microwave heating than with conventional heating when time of processing is kept constant.

Water and chicken frankfurters exhibited temperature rise after microwave processing while cake cones did not (Table 2). Temperatures rise after microwave processing may thus be considered product-dependent.

Post-heat temperature rise occurred in water and chicken frankfurters when processed in the microwave oven at both 100 and 50% power levels (Table 2). Extent of temperature rise was similar for water microwaved at 100 and 50% of power. On the other hand, extent of tempera-
TABLE 2. End point temperature, duration of heat processing, yield and post-processing temperature rise (PPTR) during dwell time of water, chicken frankfurters and cake cones heated by hot air and by microwave ovens.

<table>
<thead>
<tr>
<th>Product</th>
<th>Hot air oven</th>
<th></th>
<th></th>
<th>100% Power</th>
<th></th>
<th>Microwave oven</th>
<th></th>
<th>50% Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EPT (°C)</td>
<td>Time (min)</td>
<td>Yield (%)</td>
<td>EPT (°C)</td>
<td>Time (s)</td>
<td>PPTR duration (s)</td>
<td>PPTR (°C)</td>
<td>EPT (°C)</td>
</tr>
<tr>
<td>Water</td>
<td>20 ± 2</td>
<td>5</td>
<td>100</td>
<td>18.3 ± 2.0</td>
<td>120</td>
<td>10</td>
<td>1.3 ± 2.1</td>
<td>7.4 ± 8</td>
</tr>
<tr>
<td>1000 g</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Chicken frankfurters</td>
<td>75 ± 2</td>
<td>16</td>
<td>98</td>
<td>75.5 ± 12.4</td>
<td>30</td>
<td>45</td>
<td>8.5 ± 6.5</td>
<td>74.6 ± 9.3</td>
</tr>
<tr>
<td>45 g</td>
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<td></td>
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<tr>
<td>Cake cones</td>
<td>105 ± 6</td>
<td>30</td>
<td>89</td>
<td>106 ± 7.5</td>
<td>40</td>
<td>89</td>
<td>N.O.</td>
<td>105 ± 9.0</td>
</tr>
<tr>
<td>40 g</td>
<td></td>
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</tbody>
</table>

**Note:**
- Dwell time = time after heat processing during which product temperature continues to rise.
- PPTR was not observed in products processed by a hot air oven.
- EPT = end point temperature.
- \( \bar{x} \) of five replications = 618 W.
- \( \bar{x} \) of five replications = 278 W.
- \( \bar{x} \) of five replications = 662 W.
- \( \bar{x} \) of five replications = 294 W.
- \( \bar{x} \) of five replications = 670 W.
- N.O. = Not Observed.

**TABLE 3. Duration and extent of post-processing temperature rise (PPTR) of selected, common meat entree's after microwave cooking/heating. Values are mean± standard deviation.**

<table>
<thead>
<tr>
<th>Product</th>
<th>Location</th>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Center</td>
<td>Right</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Beef loaf pattie</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Temperature immediately after processing (°C)</td>
<td>83.1 ± 6.0</td>
<td>89.7 ± 4.6</td>
<td>90.5 ± 4.0</td>
<td>87.8 ± 5.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PPTR (°C)</td>
<td>1.3 ± 2.3</td>
<td>1.3 ± 0.6</td>
<td>1.5 ± 0.9</td>
<td>1.9 ± 1.5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Duration (s) of PPTR</td>
<td>11.0 ± 19.1</td>
<td>15.0 ± 26.0</td>
<td>24. ± 21.4</td>
<td>16.9 ± 20.3</td>
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<tr>
<td>Pork Roast</td>
<td></td>
<td></td>
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<tr>
<td>Temperature immediately after processing (°C)</td>
<td>86.7 ± 8.0</td>
<td>77.0 ± 0.0</td>
<td>73.5 ± 11.0</td>
<td>79.0 ± 8.8</td>
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<tr>
<td>PPTR (°C)</td>
<td>2.1 ± 1.7</td>
<td>2.2 ± 0.7</td>
<td>4.3 ± 6.0</td>
<td>2.9 ± 1.2</td>
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<tr>
<td>Duration (min) of PPTR</td>
<td>3.5 ± 1.8</td>
<td>12.0 ± 5.2</td>
<td>12.3 ± 13.7</td>
<td>9.3 ± 5.0</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Turkey roast</td>
<td></td>
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</tr>
<tr>
<td>Temperature immediately after processing (°C)</td>
<td>90.2 ± 3.4</td>
<td>74.0 ± 0.0</td>
<td>80.3 ± 4.5</td>
<td>82.4 ± 7.5</td>
<td></td>
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<tr>
<td>PPTR (°C)</td>
<td>2.3 ± 2.7</td>
<td>9.8 ± 2.2</td>
<td>6.3 ± 4.0</td>
<td>6.1 ± 3.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration (min) of PPTR</td>
<td>9.3 ± 6.8</td>
<td>25.5 ± 4.3</td>
<td>16.7 ± 5.6</td>
<td>16.2 ± 9.6</td>
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<td></td>
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<tr>
<td>Turkey casserole</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Temperature immediately after processing (°C)</td>
<td>N.A.</td>
<td>74.0 ± 0.0</td>
<td>N.A.</td>
<td>N.A.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PPTR (°C)</td>
<td>N.A.</td>
<td>0.0 ± 0.0</td>
<td>N.A.</td>
<td>N.A.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration (min) of PPTR</td>
<td>N.A.</td>
<td>0.0 ± 0.0</td>
<td>N.A.</td>
<td>N.A.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
- N = 3.
- Point C, Figure 3.
- Point 0, Figure 3.
- Point G, Figure 3.
- N.A. = Not Applicable.

JOURNAL OF FOOD PROTECTION, VOL. 48, MAY 1985
TEMPERATURE RISE IN HEATED FOODS

I

Beef loaf patty after microwave processing (712 W/90 sec).

II

Beef loaf patty after 41 sec. mean time of post-processing temperature rise.

Locations with a mean post-heat temperature rise of ≥ 1 C are circled.

Figure 3. Phase II: Mean (N = 3) temperature pattern in beef loaf patties (N = 3; 150g/uncaked patty) after microwave processing and after post-processing temperature rise.
ture rise was 2.1°C greater after processing chicken frankfurters in a microwave oven at 50% power than when compared to chicken frankfurters processed in a microwave oven at 100% power. Extent of temperature rise during dwell time may thus be related to power level when chicken frankfurters were considered. Further research is needed to document extent of PPTR in other products of varying size, shape and composition.

Conclusions to phase I. Based on the results of Phase I of the present study, the following hypotheses are suggested: (a) PPTR is more likely to occur in products processed in microwave ovens than in products heat processed in hot air ovens. (b) PPTR is probably dependent on type of product to be heated. (c) PPTR may be related to power level chosen for microwave-processing when certain products such as chicken frankfurters are considered.

Phase II: PPTR of common meat entrees: microwave oven

Turkey rolls exhibited the largest mean PPTR (6.1°C, Table 3) among the four products tested. Turkey casserole did not show a PPTR. When observed, PPTR, as expected, was not uniform among batches of the same product. Beef loaf patties exhibited a PPTR ≥1°C in only 5 of 16 locations observed (Fig. 3).

Other authors have reported extent and duration of PPTR in roasts that had been microwave-cooked. Ruyack and Paul (9) processed choice semitendinosus muscles in a 915 MHz, 1600 W input microwave oven and reported a 16°C/8 min PPTR in roasts covered with a polyester film and an 11°C/7 min PPTR in uncovered roasts. Uncovered pork and uncovered turkey roasts in the present study had a smaller PPTR than the PPTR of uncovered roasts reported by Ruyack and Paul (9) possibly partially due to difference in wavelength, wattage output and time of microwave cooking. Effect of wrapping on expected PPRT should received further attention.

In contrast to expectations for conventional hot air processing, minimum internal end-temperature of pork roasts was not consistently located in the center of the roast (Table 3) despite turning during processing. This was probably due to lack of homogeniety in the product (7) as well as to lack of microwave field uniformity (11). Minimum and maximum PPTRs were also not consistently found in the same locations among roasts (Table 3). In contrast to the recommendation of Kotula (5) and based on results in Table 3, PPTR is not currently recommended for use in modification of target end-temperatures when such products are intended for domestic use.

On the other hand, manufacturers of products for use in microwave ovens might consider use of minimum PPTR when Universal Product Code labels are put on exterior packaging to provide instructions to be mechanically read by microwave ovens of the future. PPTR appears to be the result of conduction heating after processing and hence is probably affected by wrapping, wattage output, time of processing, microwave wavelength, product size and shape, and type of product. Microwave cookbooks could be written to include a section on PPTR and related factors. Microwave cookbook instructions, which alert the user to PPTR, should continue to do so but should not specify lower internal end-temperatures than currently suggested by public health codes due to the lack of current data on PPTR and to the unpredictable nature of PPTR.

Conclusions to phase II. (a) Similar to conclusions in Phase I, PPTR is product dependent. (b) Quantity and location of PPTR is not constant within and among batches of the same product. (c) Knowledge of PPTR may be of value for manufacturers of products intended for heating in microwave ovens and to food processing engineers who develop mathematical models for microwave food processing. (d) PPTR data should not currently be used to reduce EPT of products prepared in domestic settings until more precise data are available concerning the effects of product and processing environments. (e) More research is needed to determine effects of product type, shape and weight, wattage output, wavelength, processing time and container on PPTR.

REFERENCES