Functional properties of marinated chicken breast meat during heating in a pilot-scale radio-frequency oven

Rakesh K. Singh and Deepti Deshpande

Department of Food Science and Technology, University of Georgia, Athens, GA, USA

ABSTRACT
Chicken breast meat is traditionally marinated to improve tenderness and juiciness. However, a significant amount of marinade is purged during cooking. It was envisioned that preheating of marinated chicken breast meat would minimize the purge due to presetting the myofibrillar proteins and will give higher cook yield. The preheating was done in a radiofrequency (RF) oven to provide uniform heating within the volume of the product, and to allow extra marinade retention. Two preheating regimens, 20–30°C and 55–60°C were selected. A 3–4% marinade gain was obtained while the meat was preheated in RF with 10% extra marinade but this gain was not significantly different in the four treatments and the control ($p > .05$). The cooked meat yields were determined as a function of programmed preheating of marinated meat in the RF oven, followed by final cooking of the product in the air impingement oven. The programmed preheated samples at 20–30°C showed higher cook yield (96.11–100.51%) as compared to the control (95.6%). However, all the samples heated at 55–60°C showed higher cook yield (100.57–109.39%). Warner-Bratzler shear tests were performed on cooked samples to determine the quality of RF preheated product, and the quality of the RF-treated product was not much different from that of the product cooked directly in a conventional air oven.

ARTICLE HISTORY
Received 19 July 2019
Revised 18 November 2019
Accepted 22 November 2019

KEYWORDS
PSE muscle; texture; myofibrillar protein; water holding; cooking

Introduction

Chicken meat is traditionally marinated prior to cooking to improve tenderness, flavor and increase shelf life.\textsuperscript{[1]} Marination is a process of infusing a solution of water, salt and other ingredients, such as phosphates and is done by injection or tumbling.\textsuperscript{[2]} Cooking of marinated meat is of great interest to processors in the poultry industry. Conventional methods of cooking heat foods externally through conduction, convection or radiation. The main disadvantages of conventional methods are longer cooking times and overheating of outer layers, because heat is transferred from outside to inside of the product. Radio-frequency (RF) heating is a form of dielectric heating generated when the product is subjected to an alternating electric field between two parallel electrodes.\textsuperscript{[3,4]} Therefore, RF heating is a good alternative to the conventional methods because of its volumetric form of heating in which heat is generated within the product, which reduces cooking times and could potentially lead to more uniform heating. RF heating is similar to microwave heating, and both are considered non-ionizing radiations, because they have insufficient quantum energy (less than 10 eV) to ionize biologically important atoms.\textsuperscript{[3]} Generally, two frequencies (915 and 2450 MHz) are used...
for microwave food processing and three frequencies (13.56, 27.12 and 40.68 MHz) are used for RF food processing.\textsuperscript{[5]}

It is reported that RF heating could be the most promising technique for continuous pasteurization of emulsion sausages in terms of penetration depth, energy efficiency, and product quality.\textsuperscript{[6]} Ryynänen\textsuperscript{[7]} concluded that RF heating could be favorable for cooking of cured whole meat products like hams, as the mode of heating is by the depolarization of ions in solution, which are plentiful in a salt-added product. Laycock et al.\textsuperscript{[8]} evaluated the influence of RF cooking on the quality of ground, comminuted and muscle meat products after being heated to a center temperature of 72°C. They concluded that RF cooking of processed meats resulted in decreased cook time, lower juice losses, acceptable color, water-holding capacity, and texture. Another study on post-cooking temperature profiles of meat emulsions\textsuperscript{[9]} suggested that uneven temperature distributions are possible in RF cooked meat products within a package. They found that the temperature differentials were two-folds higher within the RF-cooked sample relative to its steam-cooked counterparts. Zhang et al.\textsuperscript{[10]} developed a method for RF pasteurization of large diameter meat products in casings (i.e., leg and shoulder ham) and compared the sensory attributes of RF pasteurized products with the conventionally pasteurized product. It was concluded that RF-cooked hams had significantly lower water-holding capacities and higher yields as compared to their steam-cooked counterparts. In a study, Kirmaci and Singh\textsuperscript{[4]} fully cooked chicken meat in a pilot-scale RF oven and concluded that the cook time was much faster than cooking in a water bath and the marinated meat showed higher values of cook yield, moisture content, tenderness, and pH.

Cooking of marinated meat causes physical and chemical changes including the binding of water in the meat. Furthermore, processing methods including hold time after marination affect the sensory qualities of marinated cooked chicken meat. Yusop et al.\textsuperscript{[11]} found that marinated meat by tumbling followed by 18 h hold and then cooked showed significantly better sensory qualities than simply holding the marinated meat for 18 h or particle size reduction of the marinade. Moreover, the temperature during the marination may have some effect in marinade penetration to the interior of meat and higher yield. However, Fenton et al.\textsuperscript{[12]} did not observe much effect of marinade temperature in the range of \(-4°C\) to \(4°C\) on cook yield or purge loss because the temperature range was very narrow. Singh and Deshpande\textsuperscript{[13]} found that thermal denaturation of marinated chicken breast meat stored for 24 h showed one transition peak at a lower temperature (55.3°C) than two transition peaks observed at higher temperatures (58°C and 77°C) for fresh chicken breast meat. Water held in the muscle is lost during cooking when collagen surrounding the muscle fibers and muscle fiber bundle contract before the muscle protein gels.\textsuperscript{[14]} Thus, a scheduled heating sequence in the cooking of meat could minimize the release of water from the meat, and will result in a juicy-cooked product.\textsuperscript{[15]}

We envisioned that preheating of chicken meat to temperatures higher than \(4°C\) but lower than the gelation transition peak temperature range of 55–60°C may give higher cook yield and lower purge. Thus, the objective of this research was to develop the process for preheating marinated chicken breast meat in a pilot-scale radio-frequency oven: (1) To determine the amount of marinade pickup due to RF heating to 20–30°C (near room temperature), and its effect on purge, and cook yield; and (2) To develop the process of preheating marinated chicken breast meat to 55–60°C (gelation temperature of myofibrilar proteins) in the same RF oven, and its effect on marinade pickup, purge, cook yield and shear value.

**Material and methods**

**Sample preparation**

Fresh chicken breast meat (sorted and trimmed to 113.3 g pieces) was obtained from a local commercial processing plant (Mar Jack Inc., Gainesville, GA). The initial mass of fresh chicken breast meat was determined on a weighing balance (Scale Systems Inc., IL) and the meat was stored...
in a refrigerated room at 4°C until used for further processing. A relatively low-salt content marinade was prepared at room temperature of 22°C by mixing 6% salt and 1.8% sodium tripolyphosphate (STPP) in the desired amount of deionized (DI) water.\cite{4,16,17,18} The final-targeted concentrations for salt and phosphate in the product after marination were 1% and 0.3%, respectively. The marinade was chilled at 4°C until it was ready for use. Chicken breast meat and the marinade were put together in a vacuum tumbler (Model no. 1102, U-MEC Food Processing Equipment, Hayward, CA) and 92.3 kPa of vacuum was drawn with a high capacity vacuum pump. Tumbling was conducted for 20 min at 8 rpm in a 7°C processing room. The marinade addition was targeted at 20% of meat weight. Immediately after tumbling, the mass of the marinated meat was noted in order to determine the percent marinade absorption or gain. The purge loss was calculated by determining the weight of samples after storing for 24 h at 4°C after marination. The pH and total moisture values of fresh chicken breast meat, marinated meat and meat after 24 h of storage were determined. Expressible moisture was determined after 24 h of storage. Two separate experiments were performed and the experimental details for both of them is described as follows:

**Marinade retention due to RF preheating**

This study was conducted to optimize the RF heating and vacuum tumbling processes, so that the meat will absorb and hold marinade added during tumbling, and the extra marinade added to eliminate voids in the meat during heating in the RF field. The RF oven used was a Model S061B, Strayfield, England, UK. Four different treatments were performed as shown in Figure 1, and each treatment was replicated twice. Ten percent extra marinade was added in three treatments to determine the amount of absorption during preheating in the RF oven. In treatments T1 and T2,

![Figure 1. Schematic diagram of treatments for both objectives in this study.](image-url)
the samples were preheated in the RF oven to 30°C to allow penetration of marinade inside the meat tissue. Immediately after preheating, they were tumbled warm in the vacuum tumbler for 5 min for treatment T1 for the absorption of the added marinade, whereas they were cooled on ice and tumbled for 2 min in treatment T2 to determine if muscle shrinkage due to cooling may hold marinade in the meat. In treatment T3, the marinated meat at 5°C was reheated in the RF oven to 20°C, cooled on ice and then vacuum tumbled for 2 min. In treatment T4, 30% of marinade was directly added to fresh chicken breast meat and preheated in the RF oven to 30°C and then vacuum tumbled warm for 20 min immediately after the RF treatment to evaluate if the direct addition of the entire 30% marinade could be as effective as two-step addition. Preliminary experiments were conducted to determine the RF exposure needed for the meat placed in a 4-L Rubbermaid or Ultem® container to reach the target temperature. Meat temperature was measured with a type K thermocouple thermometer (Fisher Scientific, Pittsburgh, PA) after the meat was removed from the RF field. RF heating parameters were noted for each batch, which included the anode current (Ia), grid current (Ig), distance between the electrodes, conveyor belt speed and finally the RF heating rate. Immediately after RF preheating, the mass of the meat samples was determined and then the samples were stored in air-tight containers in the cold room (4°C) for 24 h. The samples were again weighed after 24 h and the amount of marinade lost as purge was recorded. The samples were then cooked in an impingement oven (model no. 1450, Lincoln Impinger, Fort Wane, IN) set at 177°C, until they reached the endpoint temperature of 80°C. A Type K thermocouple probe was inserted in the thickest part of the chicken breast meat to ascertain that the target endpoint temperature was reached. In the reference treatment (control treatment), the vacuum tumbled batch was directly cooked in the impingement air-oven after 24 h at 4°C and without RF treatment. The cooked meat yields for all the batches were determined after removal from the impingement oven and equilibration to room temperature.

Cook yield due to RF preheating to myofibrillar protein gelation temperature

The marinated chicken breast meat was first preheated in the RF field until the meat proteins were preset at 55–60°C (gelation temperature of myofibrillar proteins) followed by the final cooking to an internal temperature of 80°C in a convection oven. A Fiber-optic temperature-sensing device (UMI4, Universal Multichannel Instrument, Fiso Technologies Inc., Quebec, Canada) was used to measure and record time-temperature data during RF heating. This study consisted of four treatments that were replicated three times. The weight of each batch of breast meat was determined before heating in the RF oven. Marinated chicken meat at 4°C was placed in the respective containers (Rubbermaid or Ultem®) and exposed to the RF field until the target end-point temperature between 55–60°C (the gelation temperature of the myofibrillar proteins) was reached. Immediately after RF preheating, the meat was placed on an aluminum tray and cooked in a conventional air oven (Blodgett, Dual Flow) at 176.6°C until the center temperature reached 80°C. The meat temperature in the center of the thickest part of the meat was monitored using a type K thermocouple. After the meat end-point temperature was reached, the meat was allowed to equilibrate at room temperature and the cooked weight was measured. Six breast pieces from each batch of cooked meat were then wrapped in aluminum foil and the shear values were determined with a TA-XT2i texture analyzer. Results were reported as the mean of each of the six samples for each batch. For treatments E1, E3 and E4 as schematically shown in Figure 1, a plastic material made of polyetherimide also known as, Ultem® was used as a product holder. The fiber-optic temperature sensing probes were positioned, one at the geometric center and the other at the rear end of the container in order to measure the temperature uniformity along the length of the container. The tip of the probe was inserted in the thickest part of the breast meat. The Ultem® container was made such that it matched the area of the upper electrode. For treatment E1, the conveyor belt speed was constant at 4.0 cm/min and the product was exposed to RF as the container moved on the conveyor belt between two parallel plate electrodes. After the first run, the RF oven was stopped for 2 min and again the product was
exposed to RF until it reached the target temperature of 55–60°C. This was followed by cooking the meat in a conventional oven until the end-point temperature of 80°C was reached and the final weight after cooking was determined. For treatment E3, the Ultem® container was placed directly between the two plate parallel electrodes and the conveyor belt was kept stationary. For treatment E4, the same Ultem® container was used and the conveyor belt was kept moving at a variable belt speed of 2.0 to 4.8 cm/min. The meat was mixed in between the two runs in order to ensure uniform temperature distribution at the end of RF preheating. For treatment E2, a different container, i.e., the Rubbermaid plastic container was used and the product was exposed to RF when the conveyor belt was moving at a constant speed of 3.3 cm/min. This container was used in order to preheat three layers of product one above the other and determine the uniformity of temperature distribution. The fiber-optic probes were placed such that one of them was inserted into the meat piece on the top layer and the other one inside the piece on the bottom layer of the product in the container. A control was used in which the marinated meat was directly cooked in an aluminum tray in a convection oven until the end-point temperature of 80°C was reached.

**Measurements of physico-chemical meat properties**

**pH**
The pH of surface of chicken breast meat was measured with a direct probe method, Accumet pH meter (AR15 pH meter, Fisher Scientific, Pittsburg, PA) equipped with a flat probe (Accumet, Cat. # 13-620-289) electrode. The pH meter probe was calibrated and standardized (using pH 4.00 and pH 7.00 buffer solutions) for every batch. The pH values were obtained for fresh meat, marinated meat, RF preheated meat and meat after 24 h of storage after marination. Triplicate measurements were made and values were reported as the mean.

**Total moisture**
Total moisture values were determined with a Mettler Toledo moisture analyzer (HR73 Moisture Analyzer, Mettler Toledo, Switzerland). About 4–5 g of sample was weighed on the aluminum pan. The drying temperature was set at 90°C for the standard drying cycle for about 3 to 4 h as described in the brochure from the manufacturer. Total moisture values were obtained for fresh chicken breast meat, marinated meat, RF preheated meat and meat after 24 h of storage.

**Expressible moisture**
The filter press method was used for measuring the water-holding capacity of the marinated meat after 24 h of storage. Samples (300 ± 5) mg of 24-h stored marinated meat) were placed on a previously weighed filter paper (Whatmann no. 1) with 9 cm diameter. Then, the filter paper with a meat sample was placed between two Plexiglass plates. A load of 1.0 kg was applied for 1 min and the damp filter paper was rapidly weighed after removing the compressed meat sample. The mean of two replicates was taken as the average value for water-holding capacity, expressed as the percentage of released water (expressible moisture, EM), and calculated as according to Eq. 1:

\[
EM = \left(\frac{\text{weight of damp filter paper} - \text{weight of dry filter paper}}{\text{sample weight}}\right) \times 100
\]

**Shear value**
Warner-Bratzler Shear tests were conducted on cooked chicken breast meat as described by using a TA- XT2i texture analyzer (Texture Technologies Corp., NY). Samples were cooked, wrapped in aluminum foil and equilibrated 30 min at room temperature (22°C) as previously described. Cooked chicken breast was cut parallel to the muscle fibers from the middle portion of the breast to obtain a sample strip approximately 1.9 cm wide and 2.5 cm long. The sample thickness was the natural thickness of the cooked meat. A slotted plate was installed into a heavy-duty platform (model TA 90)
secured at the base of the texture analyzer by two thumbscrews. A shearing blade (model TA 7 WB blade) was installed to the load cell holder. The heavy-duty platform was repositioned to enable the blade to pass through the base plate. A 5-kg weight was used to calibrate the 25-kg load cell prior to the analysis and the setting was adjusted based on preliminary trials at a preset speed of 5 mm/s, a test speed of 10 mm/s and a posttest speed of 5 mm/s. Shear test was conducted by loading the blade through the sample strip to determine the maximum shear force (N) and the work of shearing (N s) based on the force deformation curve. Average of six replicates was taken as the shear value for each treatment.

**Marinade pickup (MP)**

Mass of fresh chicken breast meat was determined before marination. Immediately after tumbling, the weight of marinated meat was determined and the marinade absorption was calculated as shown in Eq. 2:

\[
MP = \frac{W_0 - W_i}{W_i} \times 100
\]

where, \(W_i\) = initial weight of meat (g), \(W_0\) = weight of marinated meat at 0 h after marination (g)

**Purge loss (PL)**

The marinated meat samples were stored at 4°C for 24 h and weighed. The percentage purge loss of marinated meat was calculated as shown in Eq. 3:

\[
PL = \frac{W_{RF} - W_{24}}{W_{RF}} \times 100
\]

where, \(W_{24}\) = weight of marinated meat after 24 h of storage (g), \(W_{RF}\) = weight of marinated meat after RF treatment (g).

**Cook yield**

The samples were cooked as previously described. The whole batch was cooked and cooked meat was allowed to equilibrate at room temperature (22°C) and weighed. Cook yields were calculated on an initial weight basis as according to Eq. 4:

\[
Cook\ yield = \left(\frac{\text{Weigh after cooking}}{W_i}\right) \times 100
\]

**Statistical analysis**

Data were analyzed using a one-way analysis of variance (ANOVA) and multiple analysis of variance (MANOVA). The SAS jump software was used for this purpose.

**Results and discussion**

**RF preheating parameters**

Marinated chicken breast meat heated in Rubbermaid plastic container from 5°C to 30°C required 25 min for treatments T1, T2, and T4 (with a heating rate of 1°C/min), while treatment T3 was heated to 20°C and it required 15 min. Cooking to a final end-point temperature of 80°C in an impingement oven for the reference treatment of marinated non-RF preheated meat required 20 min from an initial temperature of 4°C. This shows that the RF heating was slower than heating in an impingement oven. The RF heating rates are dependent on various parameters, such as distance...
between the electrodes, product holder, anode current and the grid current. The lesser the distance between two parallel plate electrodes, the greater is the anode current and the heating rates become faster. However, there is a limit to how close the electrodes can be spaced with the product present in the gap. We have observed arcing, if the electrodes become too close to each other, and a strong arc shuts down the RF generator. Therefore, the electrode spacing was set at a point where arcing did not occur. When the product was contained in a Rubbermaid container, the least possible distance between the electrodes was 9.5 cm without arcing. The anode current was 0.4 A and the grid current was 0.74 A. One possible approach to increasing the RF heating rate would require the use of a product container having the appropriate product depth and relatively low loss factor.

**Marinade gain**

Table 1 shows the marinade gain for all the treatments designed to maximize the absorption of extra marinade added during the RF preheating process. The gain values were found to be high for the control, i.e. around 17%. Although more marinade was absorbed, all of it was not retained after 24 h as the expressible moisture values and the purge values were high compared to the other treatments (Table 2), which are discussed in detail in the following sections. A 3% to 4% gain was obtained while the meat was RF preheated with the extra marinade. This was less than the 10%-added marinade although there was no free marinade left when the meat and marinade was removed from the container after RF treatment. These low values of gain could be due to losses during the treatment (evaporation) and splashing of the marinade as the container was moved to the RF oven and positioned between the electrodes. In addition, re-tumbling the meat after the RF treatment resulted in exudates of salt soluble proteins adhering to the walls of the tumbler and could not be accounted for in the final product weight. ANOVA results (Table 3) show that the gain is not significantly different in the four treatments and the control (p > .05). However, 3–4% gain in all four treatments show that during RF preheating the extra marinade added got absorbed with further tumbling for 2–5 min. This is a relevant finding in terms of marinade gain and retention for the poultry industry. In a study of temperature effect on marinade absorption in chicken meat, Palang [21] found a trend of increasing marinade absorption with increasing temperatures in the range of 4°C to 23°C, which is in agreement with our findings.

**Total moisture**

The moisture content values are given in Table 1. The total moisture was maximum in RF-treated meat (Fresh meat < marinated meat < meat after RF treatment). This affirmed that RF treatment

| Treatment | Marinade gain (%) | Fresh meat moisture (%) | Marinated meat moisture (%) | RF treated meat moisture stored for 24 h (%) |
|-----------|------------------|------------------------|---------------------------|----------------------------------------|
| T1        | 23.3 ± 0.9a      | 70.5 ± 0.3a            | 72.9 ± 0.6a               | 74.0 ± 0.4a                            |
| T2        | 23.4 ± 0.3a      | 70.4 ± 0.3a            | 73.6 ± 0.4a               | 75.12 ± 0.5b                           |
| T3        | 26.7 ± 0.7b      | 71.3 ± 0.4a            | 73.0 ± 0.3a               | 75.±0.2b                              |
| T4        | 24.1 ± 0.9b      | 70.6 ± 0.2a            | 73.0 ± 0.2a               | 73.7 ± 0.5b                           |
| Control   | 27.4 ± 1.1b      | 70.4 ± 0.3a            | 73.1 ± 0.5b               | -                                      |

Values with different letters in the same column indicate significant differences at the 0.05 level. n = 3
T1 = Marinated meat was preheated in the RF oven to 30°C, and tumbled warm for 5 min.
T2 = Marinated meat was preheated in the RF oven to 30°C, cooled on ice, and tumbled for 2 min.
T3 = Marinated meat at 5°C was preheated in the RF oven to 20°C, cooled on ice and tumbled for 2 min.
T4 = Thirty percent of marinade was directly added to fresh meat, preheated in the RF oven to 30°C and tumbled warm for 20 min.
increased the absorption and retention of marinades in chicken breast meat due to the presetting of meat proteins as observed in a few other studies.\textsuperscript{[4,21]} In other studies, the total moisture of chicken breast meat was 78\% on wet basis\textsuperscript{[22]}, and for breast fillets, it was 76.35\% on a wet basis.\textsuperscript{[23]} However, in our study, it was about 71\% for fresh meat and 73\% for marinated meat. The difference in the total moisture values could be due to several factors such as water absorbed during chilling, storage of meat in ice after deboning, or wetting of the meat after deboning.\textsuperscript{[24,25]}

**Purge loss**

Purge loss varied significantly with different treatments. Table 2 shows that the purge is significantly different in T3 as compared to other treatments and the control. In T3, the marinated chicken breast meat was preheated to a temperature of 20°C. This temperature might not be sufficient to stimulate the absorption and retention of marinade in the meat and hence the purge value is high.\textsuperscript{[12]} Whereas, in other treatments, the meat was preheated in the RF oven to 30°C and at this temperature the marinade must have been absorbed and retained after 24 h.\textsuperscript{[21]}

**pH**

The pH value of marinated meat and meat after RF treatment was similar to that of fresh chicken breast meat. The pH of marinated meat after 24 h is given in Table 2. Another study\textsuperscript{[26]} reported that the pH value for raw chicken breast fillet was approximately 5.81 pH units, that of marinated fillet equaled to 6.03 and after cooking it was 6.31 pH units. However, the study in\textsuperscript{[26]} concluded that the pH values of normal and light breast fillet were not significantly different from each other. The ANOVA results (Table 3) show that the p-value for pH is higher than 0.05 and hence it can be inferred that the pH did not vary significantly with different treatments. The Tukey test also supported this interpretation.

**Expressible moisture (EM)**

The expressible moisture values for various treatments after 24 h of storage are reported in Table 2. Higher values of expressible moisture indicate lower water-holding capacities. These results show that the expressible moisture in T1 is significantly different from the values obtained from the other three treatments (T2, T3, T4) and the control treatment. The expressible moisture in T1 is the lowest, which indicates that the water absorbed during this RF treatment was retained in the tissue. The expressible moisture value for the control is the highest. In another study\textsuperscript{[9]}, EM values were reported to be significantly lower (P < .001) for RF-cooked samples compared to steam-cooked samples. These findings were also in agreement with those of Laycock et al.\textsuperscript{[8]} for whole muscle and

**Table 2. Effect of various treatments on purge, pH, expressible moisture and cook yields for objective 1 experiments.**

| Treatment | Purge after 24 h (%a) | pH after 24 h (b) | Expressible moisture (%) | Cook yield (%) |
|-----------|----------------------|------------------|-------------------------|---------------|
| T1        | 0.0 ± 0.0\textsuperscript{a} | 6.0 ± 0.1\textsuperscript{a} | 20.9 ± 0.4\textsuperscript{a} | 100.5 ± 0.9\textsuperscript{a} |
| T2        | 0.0 ± 0.0\textsuperscript{a} | 6.0 ± 0.1\textsuperscript{a} | 31.3 ± 1.0\textsuperscript{b} | 96.1 ± 0.5\textsuperscript{b} |
| T3        | 0.1 ± 0.0\textsuperscript{b} | 6.0 ± 0.1\textsuperscript{a} | 36.7 ± 1.7\textsuperscript{b} | 99.0 ± 2.5\textsuperscript{b} |
| T4        | 0.0 ± 0.0\textsuperscript{a} | 6.0 ± 0.0\textsuperscript{a} | 36.6 ± 0.6\textsuperscript{b} | 92.3 ± 1.4\textsuperscript{b} |
| Control   | 0.0 ± 0.0\textsuperscript{a} | 6.0 ± 0.0\textsuperscript{a} | 58.5 ± 2.1\textsuperscript{c} | 95.6 ± 2.0\textsuperscript{b} |

Values with different letters in the same column indicate significant differences at the 0.05 level. \( n = 3 \)

T1 = Marinated meat was preheated in the RF oven to 30°C, and tumbled warm for 5 min.
T2 = Marinated meat was preheated in the RF oven to 30°C, cooled on ice, and tumbled for 2 min.
T3 = Marinated meat at 5°C was preheated in the RF oven to 20°C, cooled on ice and tumbled for 2 min.
T4 = Thirty percent of marinade was directly added to fresh meat, preheated in the RF oven to 30°C and tumbled warm for 20 min.
Cook yield for objective 1 experiments

The cook yield value was highest for treatment T1 and lowest for T4, as shown in Table 2. This shows that preheating of partially marinated meat and tumbling followed by additional marinade addition gave higher cook yield (T1, T2, T3) than adding the entire marinade, preheating and tumbling. Zhang et al.\cite{10} concluded that the cook yield values for leg and shoulder ham for RF-cooked samples were higher than their steam-cooked counterparts. The statistical analysis shown in Table 3 indicates that the cook yield is different from one or more treatments. The Tukey test also showed that cook yield from T1 and T3 were statistically different from other treatments and the control treatment.

Cook yield due to RF preheating myofibrillar protein gelation temperature

Time-temperature profile for RF cooking

A study on meat proteins\cite{15} reported that at temperatures between 53°C and 63°C, collagen denaturation occurs followed by collagen fiber shrinkage. Another study\cite{22}, showed that chicken breast meat yielded three endothermic transitions, the first one at 53°C and the rest at 70 and 79°C. Hence, in this study, the marinated meat was preheated in the RF oven in the range of 55–60°C in order to preset the proteins. The typical time–temperature profile for RF-heated meat using Ultem® and Rubbermaid plastic containers as product carriers are shown in Figures 2 and 3, respectively. Figure 2 shows the time-temperature profile for preheating marinated chicken breast meat in RF oven with Ultem® as the product holder. Where lower line (▀) is position of the fiber optic probe that was inserted in the meat piece at the center of the Ultem® tray and upper line (♦) is the position of fiber optic probe that was inserted in the meat piece at the rear end of the Ultem® tray. Figure 3 shows the Time-Temperature profile for preheating marinated chicken breast meat in RF oven with Rubbermaid container as product carrier. Where, one fiber optic probe was inserted in the meat piece at the bottom layer in the Rubbermaid container and another probe was inserted in the meat piece at the top layer in the same container.

It can be inferred that the heating rates were faster when Ultem® was used as a product holder as compared to Rubbermaid container. The time required to preheat the meat to the target temperature in the RF oven using the Rubbermaid product carrier is almost double that required for the product in Ultem®. However, the temperature distribution seems uniform in case of the treatment 2 (E2), which had Rubbermaid container as product holder. Hence, the Rubbermaid container can be used for RF preheating if uniform temperature distribution in different pieces along the length of the container is desired. Table 4 shows the values of anode current (Ia) and the cathode current (Ig). It can be inferred that as the distance between the electrodes is reduced, the anode current (Ia) increases and the time required for RF preheating decreases. Hence, in order to achieve faster

| Parameter         | F Value | Significance |
|-------------------|---------|--------------|
| Cook yield        | 7.78*   | < 0.05       |
| Marinade Gain     | 2.16    | 0.21         |
| Moisture          | 214.83* | < 0.05       |
| pH                | 1.1     | 0.44         |
| Purge             | 60.93*  | < 0.05       |

*indicates p value < 0.05, hence parameter varies significantly for different treatments

INTERNATIONAL JOURNAL OF FOOD PROPERTIES 1993
heating rates, the distance between the upper electrode and the product surface should be kept minimal. Treatment E4 was conducted in order to obtain faster heating rates in combination with uniform temperature distribution. The meat was mixed in between the two runs while preheating in the RF oven. The oven was stopped for 5–7 min to rearrange the meat and the temperature probes. Faster heating rates were achieved; however, the temperature distribution at the end of preheating was not as uniform as it was with the Rubbermaid product container. In the control, the marinated meat was directly cooked in a conventional air oven and the time required for cooking to the final

\[ \text{RF Heating Rate} \]

\[ \text{Temperature}(\text{C}) \]

\[ \text{Time (s)} \]

\[ \bullet \] temperature measured in a meat piece at the center of tray, \[ \diamond \] temperature measured in a meat piece at the rear end of the tray. Only a typical curve from the 9 curves is shown.

Figure 2. A typical time-temperature profile for pre-heating marinated chicken breast meat in RF oven using Ultem® as a product carrier (n = 9). • temperature measured in a meat piece at the center of tray, ♦ temperature measured in a meat piece at the rear end of the tray. Only a typical curve from the 9 curves is shown.

\[ \text{Rf Heating rate} \]

\[ \text{Temperature (C)} \]

\[ \text{Time (s)} \]

Figure 3. A typical time-temperature profile for pre-heating marinated chicken breast meat in RF oven using Rubbermaid container as product carrier (n = 3). Blue line is for temperature measurement in a meat piece at the bottom layer of the tray and pink line is for a meat piece temperature at the top layer. Only one typical curve out of 3 curves is shown.
end-point temperature of 80°C was approximately 20 min. The temperature distribution along the length of the aluminum tray after final cooking for the control varied from 71°C to 82°C. Zhang et al. [9], studied the end-point temperature distribution for RF-cooked and steam-cooked pork (Luncheon roll). These researchers reported that for steam-cooked products, the coldest point was located at the geometrical center of the samples. In contrast, for RF-cooked samples, the cold point was located at the part of the sample nearest to the bottom electrode. In our study, for the Rubbermaid container as product holder, the meat piece closest to the bottom electrode was at a higher temperature compared to the one near the surface. This could be due to the gap between the surface layer of meat and the upper electrode and due to evaporative loss as the container was not covered during cooking. Whereas, when the Ultem® container was used as the product holder, the meat at both ends of the tray, i.e. front and rear, was at a lower temperature compared to that in the center. The temperature difference in this case along the length of the container was much more than expected. This could be caused by many factors. The product in this experiment was exposed to RF fields as a batch. In the case of continuous operation, it could be possible to minimize this temperature difference. Another reason could be that the samples were heated in air, and the samples could have lost heat to the surroundings. In addition, a lack of dielectric uniformity caused by areas of products with high capacity for RF absorption can lead to runaway heating and even product arcing. Widely varying temperature along the length of the container implies the need to change the design of the product carrier. Zhang et al. [9], used a system in which circulating hot water surrounded the system that held the comminuted meat product for RF heating. These researchers also reported temperature differentials; however, they were less in magnitude as those reported by Laycock et al. [8]

Cook yield
The cooked yield values for different treatments are given in Table 4. The cook yield values were higher for E1 and for control as compared to the other treatments. The values are more than 100 as it was calculated on the green weight basis. Similar values for cooked yields were obtained by Zhang et al. [10] for RF and steam-cooked leg and shoulder ham. Statistical analysis using ANOVA (Table 5) shows that the cook yield does not vary significantly in different treatments ($p > .05$).

Texture analysis
Warner-Bratzler maximum shear force values and the work of shear for different treatments are presented in Table 4. ANOVA table shows that the $p$-value for shear force (N) and that for work
of shear (N.s) are both less than 0.05 and hence these values vary significantly with different treatments. The Tukey test results showed that the shear values for treatment E2 (Rubbermaid container as product carrier) were lower than that for the other treatments. For the treatments where Ultem® was used as the product carrier, there is no significant difference between the shear values obtained for RF preheated meat and the control. However, in case of treatment E3, the shear values are comparatively high. Work of shear was found to be the same for all the treatments where Ultem® was used as the product carrier except for treatment E3. Similar values for work of shear were obtained for treatment E2 (Rubbermaid container as product carrier) and the control. Only the stationary belt for preheating treatment produced less tender meat than all the other treatments. Effect of increasing temperature on reduction in shear force for cooked chicken meat can be explained a tenderization effect due to changes in the microstructure of meat proteins.14

Conclusion

Radio-frequency preheating of chicken meat showed a great potential for the poultry preheating of the marinated chicken breast meat. All the preheating treatments showed more marinade pickup and less purge. The moving conveyor belt treatments were better for uniformity of heating and cook yield, and the stationary belt treatment is not recommended. Preheating of meat to 55–60°C using Ultem® as the product carrier resulted in faster heating rates and allowed the meat to hold the added extra marinade as well as had higher cook yield. The preheating in Rubbermaid container was slow but uniform. Furthermore, the major advantage of preheating was to have all the chicken pieces of uniform internal temperature prior to the final cooking stage, and have higher cook yield. Hence, the target end-point temperatures in the final cooking system were reached at almost the same time for all the pieces. This avoided the overcooking of some meat pieces in the conventional process and thus maximizing the cooked product yield. The preheating could also be used in some cases to prepare intermediate product where a manufacturer can add spices and hold semi-cooked product and finish it later.

References

[1] Alvarado, C.; McKee, S. Marination to Improve Functional Properties and Safety of Poultry Meat. J. Appl. Poult. Res. 2007, 16, 113–120. DOI: 10.1093/japr/16.1.113.
[2] Bianchi, M.; Petracci, M.; Cavani, C. The Use of Marination to Improve Poultry Meat Quality. Ital. J. Anim. Sci. 2009, 8(sup2), 757–759. DOI: 10.4081/ijas.2009.s2.757.
[3] Piyasena, P.; Dussault, C.; Koutchina, T.; Ramaswamy, H. S.; Awuah, G. B. Radiofrequency Heating of Foods: Principles, Applications and Related Properties – A Review. Crit. Rev. Food Sci. Nutr. 2003, 43(6), 587–606. DOI: 10.1080/10408690390251129.
[4] Kirmaci, B.; Singh, R. K. Quality of Chicken Breast Meat Cooked in a Pilot-scale Radio Frequency Oven. Innovative Food Sci. Emerging Technol. 2012, 14, 77–84. DOI: 10.1016/j.ifset.2012.01.003.

Table 5. Analysis of variance (ANOVA) table for various parameters measured for four different treatments and control for objective 2 experiments.

| Parameter          | F Value | Significance |
|--------------------|---------|--------------|
| Cook yield         | 1.98    | 0.15         |
| Marinade Gain      | 313.06* | < 0.05       |
| Shear              | 4.94*   | < 0.05       |
| Work of shear      | 5.92*   | < 0.05       |

*indicates p value <.05, hence parameter varies significantly for different treatments
[5] Tewari, G.; Juneja, V. K. Advances in Thermal and Non-thermal Food Preservation; Blackwell Publishing: Ames, IA, 2007.

[6] Houben, J.; Schoenmakers, L.; Vanputten, E.; Vanroon, P.; Krol, B. Radio-frequency Pasteurization of Sausage Emulsions as a Continuous Process. J. Microwave Power Electromagn. Energy. 1991, 26(4), 202–205. DOI: 10.1080/08327823.1991.11688158.

[7] Ryynänen, S.: The Electromagnetic Properties of Food Materials: A Review of the Basic Principles. J. Food Eng. 1995, 26(4), 409–429. DOI: 10.1016/0260-8774(94)00063-F.

[8] Laycock, L.; Piyasena, P.; Mittal, G. S. Radio-frequency Cooking of Ground, Comminuted and Muscle Meat Products. Meat Sci. 2003, 65(3), 959–965. DOI: 10.1016/S0309-1740(02)00311-X.

[9] Zhang, L.; Lyng, J. G.; Brunton, N. P. Effect of Radio-frequency Cooking on the Texture, Colour and Sensory Properties of a Large Diameter Comminuted Meat Product. Meat Sci. 2004, 68(2), 257–268. DOI: 10.1016/j.meatsci.2004.03.011.

[10] Zhang, L.; Lyng, J. G.; Brunton, N. P. Quality of Radio-frequency Heated Pork Leg and Shoulder Ham. J. Food Eng. 2006, 75(2), 275–287. DOI: 10.1016/j.jfoodeng.2005.04.050.

[11] Yusop, S. M.; O’Sullivan, M. G.; Kerry, J. F.; Kerry, J. P. Influence of Processing Method and Holding Time on the Physical and Sensory Qualities of Cooked Marinated Chicken Breast Fillets. LWT - Food Sci. Technol. 2012, 46, 363–370. DOI: 10.1016/j.lwt.2011.08.007.

[12] Fenton, L. F.; Hand, L. W.; Berry, J. G. 1993. Effect of Marination Holding Time and Temperature on Chicken Breast Halves. Animal Science Research Report, p. 89–94, Oklahoma Agricultural Experiment Station, Stillwater.

[13] Singh, R. K.; Deshpande, D. Thermally Induced Changes in Quality of Chicken Breast Protein Fractions. J. Nutr. Food Sci. 2018, 8(4), 1–5. DOI: 10.4172/2155-9600.1000709.

[14] Kong, F.; Tang, J.; Lin, M.; Rasco, B. Thermal Effects on Chicken and Salmon Muscles: Tenderness, Cook Loss, Area Shrinkage, Collagen Solubility and Microstructure. LWT - Food Sci. Technol. 2008, 41, 1210–1222. DOI: 10.1016/j.lwt.2007.07.020.

[15] Tornberg, E.: Effects of Heat on Meat Proteins - Implications on Structure and Quality of Meat Products. Meat Sci. 2005, 70(3), 493–508. DOI: 10.1016/j.meatsci.2004.11.021.

[16] Wierbicki, E.; Deatherage, F. E. Determination of Water-holding Capacity of Fresh Meats. J. Aeric. Food Chem. 1958, 6(5), 387–392. DOI: 10.1021/jf60087a011.

[17] Zheng, M.; Detienne, N. A.; Barnes, B. W.; Wicker, L. Tenderness and Yields of Poultry Breast are Influenced by Phosphate Type and Concentration of Marinade. J. Sci. Food Agri. 2000, 81, 82–87. DOI: 10.1002/1097-0010(2000101)81:1<82::AID-JSFA783>3.0.CO;2-7.

[18] Smith, D. P.; Young, L. L. Marination Pressure and Phosphate Effects on Broiler Breast Fillet Yield, Tenderness and Color. Poult. Sci. 2007, 86, 2666–2670.

[19] Anonymous. 2002. Methods of Moisture Content Determination – Halogen Moisture Analyzer from Mettler Toledo. http://docsshare04.docshare.tips/files/3835/38359059.pdf. Downloaded on November 3, 2019

[20] Rababah, T.; Hettiarachchy, N. S.; Esvaranandam, S.; Meullenet, J. F.; Davis, B. Sensory Evaluation of Irradiated and Nonirradiated Poultry Breast Meat Infused with Plant Extracts. J. Food Sci. 2005, 70(3), S228–S235. DOI: 10.1111/j.1365-2621.2005.tb07162.x.

[21] Palang, E. Y.; Toledo. 2004. The Role of Ingredients and Processing Conditions on Marinade Penetration, Retention, and Color Defects in Cooked Marinated Chicken Breast Meat. Ph.D. Dissertation, University of Georgia, Athens, GA USA

[22] Murphy, R. Y.; Marks, B. P.; Marcy, J. A. Apparent Specific Heat of Chicken Breast Patties and Their Constituent Proteins by Differential Scanning Calorimetry. J. Food Sci. 1998, 63(1), 88–91. DOI: 10.1111/j.1365-2621.2005.tb07162.x.

[23] Qiao, M.; Fletcher, D. L.; Smith, D. P.; Northcutt, J. K. The Effect of Broiler Breast Meat Color on pH, Moisture, Water-holding Capacity, and Emulsification Capacity. Poult. Sci. 2001, 80(5), 676–680. DOI: 10.1093/ps/80.5.676.

[24] Jeong, J. Y.; Janardhanan, K. K.; Booren, A. M.; Karcher, D. M.; Kang, I. Moisture Content, Processing Yield, and Surface Color of Broiler Carcasses Chilled by Water, Air, or Evaporative Air. Poult. Sci. 2011, 90, 687–693. DOI: 10.3382/ps.2010-00980.

[25] U-chupaj, J.; Malila, Y.; Petracchi, M.; Benjakul, S.; Visessanguan, W. Effect of Tumbling Margination on Marinade Uptake of Chicken Carcass and Parts Quality. Braz. J. Poutry Sci. 2017, 19(1), 1–5. DOI: 10.1590/1806-9061-2016-0380.

[26] Qiao, M.; Fletcher, D. L.; Smith, D. P.; Northcutt, J. K. Effects of Raw Broiler Breast Meat Color Variation on Marination and Cooked Meat Quality. Poult. Sci. 2002, 81(2), 276–280. DOI: 10.1093/ps/81.2.276.