RADIO FREQUENCY COOKING OF FRESH AND MARINATED CHICKEN BREAST MEAT AND ITS QUALITY

by

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ABSTRACT

Packaged fresh and marinated chicken breast meat were cooked in the radio frequency (RF) oven at 27.12 MHz until the center of the breasts reached to 74 °C at the coldest point of the package. The effect of RF cooking on the quality, temperature distribution and heating rate of chicken breast meat were studied. RF cooked breasts were compared to the conventional cooked breasts in the water bath (WB). Moreover effect of marination and addition of ι-carrageenan on the quality of the raw and cooked chicken breast meat were investigated and compared to unmarinated breasts. The time to reach end point temperature in the RF oven was 23.8 min for 1.36 kg breasts, whereas it took 41.3 min to cook in the WB. RF cooking time was 42.4% lower than WB cooking time. RF cooking resulted in higher heating rate (2.67 °C/min when compared to 1.8 °C/min in the WB). However temperature distribution of WB cooked breasts was significantly better than RF cooked breasts. Cook yield, moisture content, pH, expressible moisture, shear value of RF and WB cooked chicken breast meat were statistically the same. However RF cooked chicken breast meat had lower a* (redness) and saturation values than their WB cooked counterparts. Non-uniform heating distribution might be the reason to observe low a* and saturation values, since more heating causes less chance of pink discoloration. Marination resulted in increase in the cook yield, moisture content, and pH value. Addition of ι-carrageenan to the marinade also increased the cook yield, moisture content of the cooked breasts. Marination increased the tenderness, meanwhile addition of ι-carrageenan made chicken breasts more tender. Neither marination nor ι-carrageenan addition affected the expressible moisture of cooked samples, as moisture retention in the meat structure was primarily due to physical changes in the protein structure.

INDEX WORDS: Radio frequency (RF); Chicken breast meat; Shear values; Color; Marination; ι-carrageenan

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DEDICATION

I dedicate this thesis to my fiancée, Mehtap.

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CHAPTER 1

INTRODUCTION

The recent statistic report of United States Department of Agriculture on poultry production showed that Georgia produced 3.36 million tons of chicken with a market value of almost $3.4 billion dollars in the 2008 (USDA-NASS 2009). Georgia is the biggest broiler producer state in the U.S. Poultry products are consumed in considerably high amounts in the U.S., 38.4 kg per capita (USDA-ERS 2009). In the 1980s, whole broiler sales were account for the half of the poultry market, whereas the share of further processed broilers in the poultry market was 10%. During last 20 years, demand for the further processed poultry products was sharply increased up to 48% (NCC 2009).

There are different ways to cook chicken breast meat such as boiling, roasting, grilling etc. Boiled chicken breast meat is used in some ethnic restaurants. After heating it up, it is served to the customer with gravy or sauce. This ensures the food safety of the cooked chicken breast meat as well as decreases the cost. In fact, adequately cooking of chicken breast does not pose food safety hazards, since spoilage and pathogenic microorganisms are inactivated. However, improper handling of the breast meat after cooking might cause food safety hazards. Therefore, packaging plays a significant role in overcoming contamination with pathogenic microorganism after cooking.

Radio frequency (RF) heating is one of the promising techniques to heat products in a short time. While RF energy heats the product rapidly, it also distributes the heat evenly through the product. In other words, heat is generated within the product, so that better temperature distribution is expected compared to conventional heating methods.

Consumer acceptability is the most important criterion for quality of ready-to-eat foods. Improving consumer acceptability is the main goal of marination of meat, poultry and fish products. Some hydrocolloids might be used in the marinade formula to enhance the flavor and texture of the cooked chicken breast meat.

The scope of this research covers the cooking procedures and instrumental quality determination of chicken breast meat cooked in the RF oven. The defined objectives of this research project are as follows:

i) Establish the cooking protocol of packaged chicken breast meat in the RF oven.

ii) Monitor the temperature distribution during the cooking of chicken breast meat in the RF oven.

iii) Compare the quality of RF and water bath cooked chicken breast meat

iv) Investigate effect of marination and gum addition on the quality of RF and water bath cooked chicken breast meat.

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CHAPTER 2

LITERATURE REVIEW

Radio-frequency Heating

Radio-frequency (RF) heating is similar to microwave (MW) heating, and is a result of application of electromagnetic waves to generate heat at regulated frequencies. The heat is generated within a product due to the friction generated by the molecular rotation of polar molecules within the product. The RF portion of the electromagnetic spectrum lies in the range of 3 kHz – 1 MHz and 1 – 300 MHz. Although the frequency range for RF is very wide, there are only three frequencies available for industrial, scientific and medical applications. These frequencies are 13.56, 27.12 and 40.68 MHz. Since wavelength and frequencies are inversely proportional, wavelengths of RF are longer than that of MW (have higher frequencies: 915 MHz, 2450 MHz, 5.8 GHz and 24.124 GHz). This results in higher penetration depths in RF compared to MW. In other words, thicker samples would be heated without surface overcooking in the RF oven thanks to deep electromagnetic power penetration (Marra et al. 2009). Since energy of RF and MW are not able to ionize biological molecules in a material, they are regarded as non-ionizing radiations.

RF heating is also referred to as dielectric heating and high frequency heating. The principle of dielectric heating is transmission of the electromagnetic waves (RF or MW) through the food, a poor electrical conductor. In the RF heating systems, food is placed within electromagnetic field between parallel electrodes. In the alternating electromagnetic field, positive ions move toward the negative region of the electric field and the negatives ions toward the positive region. However, the polarity of electric field changes about 27 million times in a second for 27.12 MHz causing oscillation of ions backward and forward in the product. As the phenomenon of ionic depolarization, dipolar rotation is seen during dielectric heating. Dipolar molecules, such as water tend to align themselves appropriately according to polarity of the electric field. Changing of polarity of electric field causes continuous realignment of dipole molecules that results in friction between molecules and heat is generated within the product. Ionic depolarization is the main heating mechanism in the RF heating; on the contrary both ionic depolarization and dipole rotation are the heating mechanism in the MW heating (Piyasena et al. 2003; Marra et al. 2009).

Transfer of heat energy occurs by convention and conduction from hot medium to product in the conventional heating systems. In contrast to conventional heating, volumetric heating is observed in the RF heating systems by generation of heat inside the product due to the electromagnetic field. Volumetric heating might be defined as simultaneously heating inside and outside of the product approximately at the same heating rate. This prevents overheating of outside of the product (Brunton et al. 2005). However, uneven temperature distributions was observed in RF cooked meat products (Zhang et al. 2004).

RF can heat large and thick products better than MW because of its higher penetration depth. Moreover, its reduced cost is another advantage over the MW (Ohlsson 1999). Arcing, an electrostatic discharge as charges jump from one point to another point via dielectric breakdown (Parker et al. 2004), is the main problem that might occur during RF processing.

Dielectric Properties

Heating of foodstuff in the RF is related to its dielectric properties. Absorption and distribution of electromagnetic energy can be explained by the dielectric properties. Since foods are non-magnetic materials, permittivity (ε, complex permittivity) is the parameter that characterizes their interaction with the electromagnetic field. Permittivity can be expressed as;

$$\varepsilon = \varepsilon' - j\varepsilon'' \qquad (2.1)$$

where, ε' stands for dielectric constant, unique and constant for any material at a specific frequency under constant conditions. Dielectric constant is the ability of a material to store energy from the electric field. Dielectric loss factor (ε'', the imaginary part of the complex permittivity) is a measure of energy loss due to energy absorption and heat generation in the material passing through the electrical energy field. Another descriptive dielectric parameter is the loss tangent (or, the dissipation factor) of the material. Nelson et al. (2007) reported the dielectric constant and loss factor of the chicken breast meat as 100 and 510, respectively, at 26 MHz at 25 °C. Whereas the dielectric constant and loss factor of the marinated (15%) chicken breast meat were reported as 105.4 and 967.8 respectively at 27.12 MHz at 20 C (Lee et al. 2008a). The ratio of dielectric loss factor and dielectric constant of a material expresses the loss tangent, and it equals to the tangent of dielectric loss angle (tanδ). Hence;

$$\tan\delta = \varepsilon''/\varepsilon' \qquad (2.2)$$

Since foods are conductive materials, ionic depolarization is observed in the food material when exposed to electric field. Therefore, there is a relationship between electrical conductivity and the dielectric loss factor. Electrical conductivity, σ, (in S/m) can be formulated as;

$$\sigma = 2\pi f \varepsilon'' \tag{2.3}$$

where $2\pi f$ can also be expressed as angular velocity (ω) in rad/s (Nelson and Datta 2001; Marra et al. 2009).

The electric field distribution in the product can be measured by power absorption of the material. This can be formulated as (UIE 1992);

$$P = 2\pi f E^2 \varepsilon_o \varepsilon'' \tag{2.4}$$

where P = power density (W/m^3), f = the applied frequency (Hz), E = electric field strength (V/m), ε_o = the permittivity of free space (8.85 x 10^{-12} F/m) (Orsat et al. 2004).

Penetration depth is defined as the distance that an electromagnetic wave can penetrate perpendicular from the surface to bottom of the material as its power decreases to 1/e (1/2.72) of its initial power at the surface. The penetration depth, d_p, (in m) can be calculated by;

$$d_p = c \Big/ \left[2\pi f \sqrt{2\varepsilon'} \sqrt{\sqrt{1 + (tan\delta)^2} - 1} \right] \tag{2.5}$$

where c is the speed of generation of electromagnetic waves in a vacuum, 3 x 10^8 m/s. When the dielectric constant and dielectric loss factor is low, the deepest penetration depth is observed (Bengtsson and Risman 1971; Lee et al. 2008a). Penetration depth is a crucial dielectric property of a material affecting the uniformity of heat in the RF heating as well as sample size.

Larger penetration depth than sample size results in uniform heating with little temperature differential in the final product. In contrast, smaller penetration depth with respect to sample size causes limited heating on the near surface of the product resulting in non-uniform heating. That is very similar to conventional heating (Sumnu 2001).

Factors Affecting Dielectric Properties

The dielectric properties are dependant on frequency, temperature, water content and chemical composition and structure of the food. Water content of the material is the most important factor affecting the dielectric properties of foods. Electrical conductivity (σ) and penetration depth (d_p) are function of frequency, as mentioned above in the equations 2.3 and 2.5. In addition, polarization of molecules affects the dielectric properties due to frequency. There is no certain pattern that dielectric properties follows as frequency increased or decreased. Several studies showed that the dielectric constant and loss factor of most foods decrease in the RF region by increasing the frequency (Guan et al. 2008; Lee et al. 2008a; Nelson et al. 2007; Wang et al. 2008). However, it was also reported that increasing frequency results in increase in the dielectric loss factor of some foods, like fresh honeydew melon, watermelon and cantaloupe, in 1 – 20 GHz region (Nelson et al. 2008).

The dielectric properties depend on the temperature, as it affects the relaxation process. Relaxation time (τ) can be defined as period for the dipoles to turn back to their original orientation when electromagnetic field is removed (Nelson and Datta 2001). The relaxation time decreases with rise in the temperature. That causes higher dielectric constant values to be observed. Even though frequency of the electromagnetic waves is important to clarify the effect of temperature rise on the dielectric loss factor, other factors such composition of the food might mask the effect of temperature (Nelson and Datta 2001).

Free water found in the structure of food causes decrease in the dielectric constant as temperature rise. In contrast, the dielectric constant increases due to bound water with increasing the temperature. On the other hand, the dielectric loss factor increases with increasing temperature. In fact, ionic and dipole loss are the two factors that determine the dielectric loss factor. Addition of salt or any other ions, i.e. increasing the ash content, decreases the dipole loss component while increasing the ionic loss component. Rise in the temperature increases the ionic loss factor and decreases the dipole loss factor. Mostly, however, ionic loss is dominant over the dipole loss. As the dielectric properties of turkey meat was predicted (Sipahioglu et al. 2003), dielectric properties of other foods might also be predicted according to temperature, ash content and moisture content or water activity.

Nelson et al. (2007) measured the dielectric properties of fresh chicken breast meat at different temperature (5 °C to 85 °C) and frequency (10 MHz to 1.8 GHz). They were not be able to measure the dielectric properties over 65 °C due to changes in meat. In their study, the dielectric constant and loss factor of the chicken breast meat decreased by increasing the frequency at any temperature. However, effect of temperature depended on the frequency. Temperature rise at frequencies below 200 MHz resulted in increase in the dielectric constant and decrease in the dielectric loss factor. Above 200 MHz, the dielectric constant declined with increasing temperature. On the other hand, increase in the dielectric loss factor was observed with increasing the temperature for both frequencies above and below 200 MHz (at 26 MHz and 1.8 GHz).

Lee et al. (2008a) investigated effect of marination on the dielectric properties of chicken breast meat at different temperature (1 °C – 70 °C) and frequencies (13.26 MHz – 915 MHz). Marination had no effect on the dielectric constant at RF region, but caused increase at 915 MHz. Marinated chicken breast meat had greater dielectric loss factor than fresh chicken breast meat at all frequencies due to rise in the ash content of the meat. In a way similar to that of the dielectric loss factor, loss tangent of marinated chicken breast meat was higher than that of fresh chicken breast meat. On the contrary, penetration depth was higher in the fresh chicken breast meat when compared to marinated meat.

More recently, the dielectric properties of different beef meat blends were studied (Farag et al. 2008). It was found that the dielectric properties were greater at RF frequency, especially at 27.12 MHz, than those properties in the MW region. Composition of the meat blend played significant role on the dielectric properties as well as frequency. Despite high protein and fat content of meat, water was the main factor to influence the dielectric properties. RF energy is easily absorbed by water, having polar structure, with respect fats. Because of its non-polar structure, contribution of fat to the dielectric properties is relatively lower than that of moisture and ash content.

Importance of Dielectric Properties

The effect of dielectric properties can be expressed as the following equation:

$$\Delta T = 2\pi t f \varepsilon_o \varepsilon' tan\delta E^2 / c_p \rho \qquad (2.6)$$

where ΔT = temperature increase (°C), t = total time to increase temperature (s), f = frequency of applied electromagnetic wave, ε_o = the dielectric constant of vacuum (8.85 x 10^{-12} F/m), ε' = the dielectric constant of material to be heated, tan δ = loss tangent, E = electric field strength (V/cm), c_p = specific heat of the material to be heated (J/kg-°C) and ρ = density of the material to be heated (kg/m^3).

It can be inferred from the equation (2.6) that temperature rise can be increased by higher loss tangent, i.e. higher dielectric loss factor (Piyasena et al. 2003). Furthermore, low dielectric loss factor, i.e. less dissipation of energy into heat, causes poor heating of a material.

Increase in the dielectric loss factor due to rise in the temperature of product causes thermal runaway. Thermal runaway can be explained as accelerated heating on warmer regions of product. That is the main reason to have non-uniform heating in the RF heating systems. Therefore, for the moist foods containing salt and other ions should be considered while designing the RF applicator to prevent thermal runaway (Tang et al. 2005).

Applications of RF Heating in Food Processing

Early applications of RF heating technology to the food industry date back to 1940s. Cathcart et al. (1947), Kinn (1947), Moyer and Stotz (1947) were the first researches to integrate RF technology to the food processing. The first applications include cooking of processed meat, blanching the vegetables, heating of bread slices and thawing frozen eggs, fruits, vegetables and fish. Pircon et al. (1953) successfully achieved the pasteurization of meats with 56.6% of energy conversion efficiency in the RF heating system. RF heating was used to thaw fish and meat products in the 1960s (Jason and Sanders 1960; Sanders 1966). Bengtsson et al. (1970)

pasteurized the packaged cured hams at 60 MHz. Integration of RF heating to the drying process of baked products was studied in 1990s (Rice 1993; Mermelstein 1998). Detailed summary of RF application in the food industry was summarized by Zhao et al. (2000) and Piyasena et al. (2003). Furthermore review of recent works on RF applications was discussed by Marra et al. (2009).

As mentioned above, RF heating systems have been studied in meat processing since 1947. Houben et al. (1991) proposed continuous pasteurization process for sausage emulsions at 27.12 MHz using two power generators at 10 and 25 kW. They achieved very high heating rate up to 40 °C/min, so that total process time was 2 min. Even though pasteurization process time was very short, lethal effect of RF heating on selected microorganism was comparable to that of conventional heating. In addition to lethal effect, product appearance and taste were good. Recently, Orsat et al. (2004) studied pasteurization of hams in the RF oven and the storage of packaged hams. RF generator power (at 27.12 MHz) gradually decreased from 600 W to 150 W for the hams heated up to 75 °C. Target temperature was reached in 5 min, and hams were hold at that temperature for additional 5 min. Pasteurized hams were packed into three different packages and stored. Results showed that pasteurization in the RF oven was improved the quality of hams with proper packaging.

Several articles were published in the recent years about production of fully cooked meat products by RF heating (Laycock et al. 2003; Tang et al. 2005; Zhang et al. 2004; Brunton et al. 2005; Zhang et al. 2006). In those publications meat products were fully cooked by RF heating systems and quality of cooked meat was determined by instrumental and sensory analysis. Lyng et al. (2007) reduced the temperature differential between the different regions of RF cooked encased meat emulsion by using water circulated cell design with secondary electrodes. Secondary electrodes were used to focus electromagnetic field on the product. In that study, RF cooking process was also optimized by adjusting the RF oven power output, volume of surrounding water, temperature of initial water and distance between electrodes. 76% reduction in cooking time was achieved in the RF oven heating when compared to steam oven cooking.

Even though many possible applications of RF heating were studied, there are few applications in industrial scale. The most common usage of RF heating in the food industry is in post finish drying of snacks. Further studies are required for integration of RF technology to the current production lines. Although heat is internally generated within the product, occurrence of non-uniform heating is one of the biggest problems to be solved in the RF heating. For instance, Birla et al. (2004) offered rotation of apples and oranges by series of water jets to reduce the negative effects of irregular geometry of fruits. By the help of this simple adjustment of the process, they were able to control pest on the fruits regardless of their irregular geometry. It is also stated that uniformity of the heating was improved by continuous movement of fruits.

Properties of Chicken Breast Meat

Chemical composition of the chicken breast muscle after rigor mortis includes 75% water, 19% protein, 3.5% soluble non-protein substances and 2.5% fat. These percentages might vary with respect to several factors such as age, sex of chicken (Lawrie 1991). Diets of the chickens are determined to increase the protein content and reduce the fat content of the chicken. Ultimate tenderness, color and cook yield of the chicken breast meat are affected by aging and chilling type (Lee et al. 2008b). Young and Lyon (1997) stated that aging prior to marination resulted in lower cook loss and shear values than non aged breasts. Furthermore redness of the cooked breast was decreased by aging. Air chilling reduced the cooking loss when compared to cooking loss of water chilled chicken breasts. This was expected since water chilling causes water uptake by the breast meat (Lee et al. 2008b). In that study, consumers liked one of the air chilled and one of the water chilled breast meats more than others.

Light appearance, soft texture and low moisture retention are observed in some chicken breasts. This phenomenon is called as pale, soft and exudative (PSE) meat. Barbut et al. (2005) and Qiao et al. (2002) showed that PSE meat had lower lightness (L*) value and pH than normal breast meat. Moreover, it was stated that cooked PSE meat had higher shear value than normal cooked meat (Barbut et al. 2005).

Meat Proteins

Meat with its 19% protein content is one of the best protein sources for human diets. The proteins in the meat can be classified into three groups with respect to their solubility properties. These groups are sarcoplasmic, myofibrillar and connective tissue proteins. Sarcoplasmic proteins, also called as water soluble proteins (WSP), are composed of myoglobin, albumin, haemoglobin and the enzymes regulating glycolytic pathway like pyruvate kinase and ceratine kinase. Myofibrillar proteins, insoluble in water, are soluble in the concentrated salt solutions. Myosin and actin are responsible for 75% of the myofibrillar proteins. Moreover, actomyosin is formed during contraction of muscle by these two protein. In the presence of ATP, bonds between myosin and actin are broken and muscle will be in a relaxed state. The third group, connective tissue proteins, consists of collagen, reticulin, sarcolemma and elastic fibers (Lawrie 1991; Forrest et al. 1975).

Heating Effect on Meat

Heating causes physiochemical changes, such as cooking loss, denaturation of proteins and shrinkage of sarcomere and proteins, to occur in the meat tissue. Texture, water holding capacity, color, flavor and the final properties of cooked meat significantly changes due to thermal effects. For example color will change due to denaturation of myoglobin at around 60 °C (Palka 2004; Bejerholm and Aaslyng 2004).

Heating has different effects on meat proteins with respect to their structure. Since its high protein content, texture of meat tissue is strongly related to the meat proteins. In general, tenderness of the meat is determined by the myofibrillar and connective tissue proteins. Degradation of tertiary protein structure of collagen results in rise of its solubility during heating. That occurs at between 53 °C – 63°C and results in tenderization of meat. In contrast, solubility of myofibrillar proteins are decreased due to aggregation of proteins during heating. Therefore denaturation of myofibrillar proteins, which happens in between 30 °C and 50 °C, causes toughening (Obuz et al. 2003; Bejerholm and Aaslyng 2004; Lawrie 1991).

The other effect of heat on meat tissue is shrinkage of proteins. Transverse and parallel shrinkage are observed due to denaturation of myofibrillar and connective tissue proteins during heating. Transverse shrinkage is seen about 50 – 60 °C, on the other hand shrinkage occurs parallel to the fiber after 70 °C (Wattanachant et al. 2005). Barbera and Tassone (2006) proposed measuring the meat cooking shrinkage as a new meat quality parameter. They underlined the importance of measuring the shrinkage itself is more important than reporting the water holding capacity, cooking loss or drip loss instead.

While conformational changes of proteins are observed, water is released during cooking, which is called cooking loss. It starts around 40 °C, and the greatest cooking loss is seen between 50 °C and 70 °C because the high pressure generated due to shrinkage of connective tissue expels water. Then cooking loss development falls above 70 °C (Bejerholm and Aaslyng 2004; Tornberg 2005). The higher end point temperature of the cooked meat the greater the cooking loss. Release of water causes loss of free acidic groups so that pH of meat increases during cooking (Lawrie 1991).

Tenderness is one of the most important quality attribute of the cooked meat. Beside the sensory evaluations, several instrumental analysis methods are used to predict the tenderness of meat such as Warner-Bratzler, Allo Kramer and razor blade shear tests (Cavitt et al. 2005).

Process of Marination

Marination is one of the traditional culinary techniques. It is used to meet consumer expectations by tenderizing and improving the flavor and juiciness of the chicken breast meat. Main constituents of marinade are salt, different kind of phosphates and obviously water. It might also contain hydrocolloids, water binders, flavor enhancers and antimicrobials. The main aim for marination is improving the texture, decreasing the fluid and cook loss (Lemos et al. 1999).

Still-marinating, tumbling and injection methods are the best known marination processes. Still marinating, also called as soaking or immersion, is the simplest technique to marinate meats. Still-marinating process is simply immersion of food in brine solution. Although it requires long processing time (8-12 h for chicken breast meat and 4-8 h for chicken legs), this method might be used because of its much lower investment cost. It also results in lower cooking loss when compared to tumbling process. Having lower and slow marinade pick up rate during marination is a major disadvantage of the still-marinating process (Lemos et al. 1999; Chen 1982).

Another method to marinate meat is tumbling process. The main function of tumbling is extraction of salt soluble proteins such as actin and myosin, by mechanical massaging. Since proteins have ability to hold water in their structure, juiciness of the meat is increased (Babji et al. 1982). Higher pick up rates of marinade can be achieved by tumbling under vacuum. Pores in the meat are opened and superficial tension is reduced by air removal from the interface of meat. Tumbling time, rotation per minute, amount of marinade and temperature affect the pick-up of marinade. In-bag marination is a developed application of tumbling process which reduces variation in marinade absorption (Santolaya 1996).

Injection method gives more control over the marination process. In this method, exact amount of marinade is injected to the meat through needles. Injection is a time saving process. Furthermore, injection method also allows remaining marinade to be reused. Combination of injection and tumbling can also be used to marinate meat (Santolaya 1996).

Functions of Marinade Components

Salt and phosphates are the main component of the marinade. Generally NaCl is used as a salt component. NaCl is used to tenderize the meat and improve the flavor. It increases the solubility of salt soluble proteins; therefore it improves water binding capacity of the meat tissue. It might also help to preservation of the meat by decreasing the water activity. Amount of salt to be added in the marinade is determined according to palatability of finished product, since it had adverse effect on its taste after some point (Alvarado and McKee 2007; Lemos et al. 1999).

Phosphates are used to increase water holding capacity and cook yield. It also improves the tenderness of the cooked meat. Sodium acid pyrophosphate (SAPP), sodium tripolyphosphate (STPP) and sodium hexametaphosphate (SHMP) are some examples of phosphates used in the marinade. STPP is the most common used phosphate in the marinade because of its economy and solubility (Alvarado and McKee 2007). Zheng et al. (2001) investigated effect of different type of phosphate on the quality of cooked chicken breast meat. Tetrasodium pyrophosphate (TSPP) injected breast had the highest cook yield, but it was not soluble in high salt concentrated marinades. STPP and TSPP injected breasts showed same effects on moisture content, purge, expressible moisture and weight increase. SHMP injected breast had the lowest marinade pickup. Salts and phosphates have synergetic effects on water retention in the meat tissue and cook yield when they used in the same marinade. Dhanda et al. (2003) reported that marinated elk (*Cervus elaphus*) meat with STPP and NaCl resulted in higher cooking yield and more tender cooked meat.

Other components, like hydrocolloids, might also be used in the marinade. Zheng et al. (1999) studied effect of pectin injection on the quality of raw and cooked chicken breast meat. Results showed that only STPP injected breast meat had the highest cook yield, marinade pickup and moisture content. Injection of pectin resulted in higher marinade retention than SAPP injected breasts, whereas it had lower marinade pickup. Even though all marinated breasts showed lower shear values than noninjected control breasts, STPP injected had lower shear values than the breast injected with pectin.

Carrageenan and its Functions

Gums retain water in their structure and interact with other macromolecules by intermolecular forces such as hydrogen, hydrophobic and electrostatic bonds. These properties are responsible for general usages of gums in the food industry as a thickening agent, gelling agent, suspending agent and stabilizer (Sanchez et al. 1995).

Carrageenan is a seaweed extract and a hydrocolloid. κ-, ι- and λ-carrageenan are the major type of the carrageenan. Properties of this carrageenan types differ. Even though hot aqueous solutions of κ- and ι- carrageenan can form gel upon cooling, λ-carrageenan does not have ability to gel. The pH value of carrageenan depends on the refining process. Alkali treatment (such as KOH) will increase the pH of refined ι-carrageenan; meanwhile alcohol treatment does not affect its pH. Furthermore carrageenan does not have any isoelectric point, i.e. it is negatively charged at all medium pH. Therefore formed protein and carrageenan complex precipitates at below the isoelectric point of protein (Glicksman 1969).

DeFreitas et al. (1997) studied the properties of salt soluble meat protein (SSMP) gel with κ-, ι- and λ-carrageenan. Harder texture and greater moisture retention were observed when κ-carrageenan added to the SSMP gel. Electron microscopy images of the gel showed that physical rearrangement of κ-carrageenan and SSMP molecules leads to that improvements.

Packaging for Radio-frequency Cooking

Packaging is the most essential part after production of the food. Package not only contains the product, but also protects the product, communicates to the consumer and makes it easy to handle. Developments in the food processing led to developments in food packaging. Using microwave energy to heat the products resulted in microwaveable packages to be produced. Packaging material can transmit, reflect or absorb the microwave energy. All polymers that are used in food packaging transmit the energy, so that energy is absorbed by the food product. However, increase in the temperature of the product causes the rise in the temperature of the package material. Hence package materials should have resistance up to certain temperature according to process type. In cooking purposes, package material should be resistant to 120 °C. Retortable pouches will provide temperature resistance and allows energy to be absorbed by the food, even though it contains AlO_2 which is used as an oxygen barrier to have long shelf life of the food product (Robertson 1993).

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CHAPTER 3

RADIO FREQUENCY COOKING OF FRESH AND MARINATED CHICKEN BREAST MEAT AND ITS QUALITY[1]

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Abstract

Packaged fresh and marinated chicken breast meat were cooked in the radio frequency (RF) oven at 27.12 MHz until the center of the breasts reached to 74 °C at the coldest point of the package. The effect of RF cooking on the quality, temperature distribution and heating rate were studied. RF cooked breasts were compared to the conventional cooked breasts in the water bath (WB). Moreover effect of marination and addition of ι-carrageenan on the quality of the raw and cooked chicken breast were investigated and compared to unmarinated breasts. The time to reach end point temperature in the RF oven was 23.8 min for 1.36 kg breasts, whereas it took 41.3 min to cook in the WB. RF cooking time was 42.4% lower than WB cooking time. RF cooking resulted in higher heating rate (2.67 °C/min when compared to 1.8 °C/min in the WB). However, temperature distribution of WB cooked breasts was significantly better than RF cooked breasts. Cook yield, moisture content, pH, expressible moisture, shear value of RF and WB cooked meat were statistically same. However, RF cooked meat had lower a* (redness) and saturation values than their WB cooked counterparts. Marination resulted in increase in the cook yield, moisture content, and pH value. Addition of ι-carrageenan to the marinade also increased the cook yield, moisture content of the cooked breasts. Marination increased the tenderness, meanwhile addition of ι-carrageenan made chicken breasts more tender. Neither marination nor ι-carrageenan addition did not affect the expressible moisture of cooked samples, as moisture retention in the meat structure was obtained due to physical changes in the protein structure.

Keywords: Radio Frequency (RF); Chicken breast meat; Shear values; Color; Marination; ι-carrageenan

Introduction

Radio Frequency (RF) heating includes the heating of nonconductor in an electromagnetic field. Electric energy is converted into electromagnetic field and food is introduced to that field in between the upper and lower electrodes. RF heating is conducted at frequencies between 1 – 300 MHz, however, regulations do not allow use of all frequencies in that range. Allowed RF waves have lower frequencies such as 13.56, 27.12 and 40.68 MHz, but they have longer wavelength with respect to microwaves (Decareau 1985). There are two heating mechanisms in dielectric heating: ionic depolarization and dipole rotation. Both mechanisms can be explained by the effect of polarity change of electric field. In ionic depolarization, negative ions in the food try to move toward the positive regions of electric field. As polarity changes, oscillation of ions causing heat generation by friction takes place. On the other hand, polar molecules simultaneously realign themselves according to polarity of the field that causes the dipole rotation of molecules. Like ionic depolarization, friction due to dipole rotation results in heat generation in the food (Marra et al. 2009).

RF heating, is a promising method, provides rapid heating patterns in foods. In RF heating, heat is generated within the product, therefore over processing that might happen during conventional heating is avoided. Furthermore, there is no residual temperature in the heating medium when the RF oven turned off. Despite its many advantages, arcing and thermal runaway are the main problems of RF heating (Zhao et al. 2000).

RF heating mainly depends on the power of the RF generator and dielectric properties of the foods. In addition, dielectric properties of food also depend on the water and ash content. In their research, Zhuang et al. (2007) concluded that the dielectric properties of chicken breast meat were dependant on both frequency and temperature. Muscle type affected all of the dielectric properties of chicken breasts, whereas deboning time affected the loss tangent. In another study, dielectric properties of marinated and fresh chicken breast meat were discussed (Lee et al. 2008). It was stated that marination of chicken breast meat increased the dielectric loss factor, whereas it did not have any effect on dielectric constant. Furthermore, they reported decrease in the penetration depth of marinated chicken breast meat.

Marination is used to have better palatability by improvements in the tenderness, the flavor and the juiciness of the meat products (Lemos et al. 1999). The most common constituents of marinade are salt and phosphate. They tenderize the meat products by unfolding the proteins due to shifting the pH further away from the isoelectric point of proteins. Unfolding of proteins causes increase in the water retention of muscle tissue (Alvarado and McKee 2007). As well as improving the quality, marination also increases the cook yield of chicken breast meat (Qiao et al. 2002; Zheng et al. 1999). Xiong and Kupski (1999) indicated that marination of chicken filets with phosphate solution increased the cook yield regardless of NaCl content of marinade.

Since RF heats the product rapidly, RF cooking of fresh and marinated chicken breast meat would sharply decrease the cooking time with respect to water bath (WB) cooking. The purposes of this study were first to develop a RF-cooking protocol for chicken breast meat, and then, to evaluate the quality of product by comparing with the conventional cooked breast meats. Effects of marination and addition of ι-carrageenan on the quality of cooked chicken breasts were also studied.

Materials and Methods

Chicken Breast Meat Preparation

Six batches of 9 kg boneless skinless fresh chicken breast meat was obtained from a local poultry processing plant (Mar Jack Inc., Gainesville, GA). Each batch of chicken breast meat was stored in the cooler at 4 °C for 2 to 24 hours, and then further processed. Five different treatments were investigated to determine the efficiency of cooking. Each treatment was replicated from different batches of chicken meat. Detailed experimental design of this research is given in Appendix A. In the first treatment (Fresh), unmarinated fresh chicken breast meat was packaged immediately after taking out from the cooler. Chicken breast meat was marinated by using different formulas and targeted pick-up levels. Composition of marinade and pick-up of each treatment are given in Table 3.1. The goal was to achieve 15% pick-up after marination in the second and third treatments (M15 and M15-G). Marinade containing 7.6% salt and 2.3% sodium tripolyphosphate (STPP) was used for M15 condition. In addition to the marinade formula for M15, 1.9% semi refined ι-carrageenan (S-100Fi, Ingredient Solutions Inc., ME) was added into the marinade of M15-G. On the other hand, the fourth and fifth treatments (M20 and M20-G) had 20% targeted pick-up level after marination. Marinade for M20 condition was composed of 6% salt and 1.8% STPP. In addition to marinade formula of M20, 1.5% gum was added into the marinade of M20-G condition. After marination process, targeted final concentration for salt and STPP were 1% and 0.3% respectively for M15, M15-G, M20 and M20-G conditions. Furthermore, final gum concentrations for M15-G and M20-G conditions were 0.25% of final product weight. Marination processes were done in the 7 °C processing room. Required amount of chicken breast meat was weighed on a balance (Scale Systems Inc., IL) and proper marinade was prepared according to its weight. Marinade was prepared following the order: water, STPP, then salt and finally ι-carrageenan added. After preparation of marinade solution, it was chilled to 4 °C. Then, both chicken breast meat and marinade were placed in a vacuum tumbler (Model no. 1102, U-MEC Food Processing Equipment, CA). 692.30 mm Hg vacuum was drawn with a high capacity vacuum pump and tumbling occurred at 8 rpm for 30 min. After tumbling, weight of marinated meat was measured to check marinade pick-up level. Marinated or unmarinated fresh chicken breast meat was packaged in 1.36 kg (3.00 lb) and 2.27 kg (5.00 lb) retortable packages (Sealedair Corp., SC), under 700 mm Hg vacuum by a vacuum sealer (Henkelman, Hertogenbosch Netherlands). Package dimensions were 28 x 29.2 x 2.3 cm^3, and 36.8 x 29.2 x 2.8 cm^3, for 1.36 kg and 2.27 kg respectively. Then packages were stored in the cooler 0-3 hours and then placed in the RF oven and water bath (WB) to cook.

Packaging and Temperature Measurement

In the preliminary experiments, different types of packages such as, ovenable, retortable and cook-in-bags, from Sealedair Company and Floeter Inc. (Elk Grove Village, IL) were used to select the proper package. Some part of the ovenable and cook-in-bag packages was melted during RF heating. Although the packages composed of polyethylene terephthalate (PET) and cast polypropylene (CPP) were very reliable to cook, it was not possible to use them due to limited size of packages. Preliminary experiments showed better results for retortable pouches. Retortable pouches used to cook chicken breast meat were obtained from Sealedair Company (Duncan, SC). Retortable pouch was composed of three layers with adhesive in between them. The pouch structure consists 12 μm PET coated with aluminum oxide, 25 μm biaxially oriented nylon (BON) and 100 μm retortable CPP. Fiber optic temperature probes (Fiso Tech. Inc., Canada) was used to monitor the temperature during the RF cooking. Whereas temperature of the breast meat was monitored by thermocouples (type K, Fisher Scientific) in the WB cooking. A hole was made on one side of pouches by a #5 brass cork borer. Then, a stuffing box (C-5.2D, Eucklund-Harrison Tech., FL) was placed on the pouches, so that either fiber optic cable or thermocouple could be inserted into the package.

RF System

The experiment was performed in the RF oven (Model S061B Strayfield Ltd, Reading, UK) operating at 27.12 MHz frequency. RF oven consists of a RF generator, two electrodes and a conveyor belt. Product and container were placed in between the upper and lower electrodes. Upper electrode was built in such a way that distance between two electrodes was adjustable. Cooking was done batch-wise, thus conveyor was turned off. The power output of RF oven was 6 kW.

RF Cooking Protocol

Preliminary experiments were done to find out the best method to cook chicken breast meat in the RF oven. Initially, the heating was tried with air medium around the breast meat so that the heating rate of product would be high. However, the arcing and melting of the package caused failure in cooking, and made it impossible to cook in the air medium. Brunton et al. (2005) also reported failure to cook comminuted pork meat product in the air medium in the RF oven. Water immersion cooking was suggested to avoid arcing problem. Packages were immersed in the reverse osmosis (RO) filtered water (Water and Power Tech. Inc., Columbia, SC) added in high density polyethylene tray type containers (Photoquip Inc., FL). Dimensions for the trays were 39.4 x 34.3 x 6 cm^3 and 43.8 x 36.2 x 6 cm^3 for 1.36 and 2.27 kg packages, respectively. Although sufficient amount of water was added, some part of the package floated out of the water, and RF energy melted that area of the package when the temperature of the product reached around 50 °C. That was due to ballooning by expansion of vapor generated inside the packages. In order to prevent packages to float up, customized parallel spacers, made from polyetherimide, were made to attach the top of the container. Even though it delayed arcing, problem could not be completely solved. A polyetherimide plate was placed under the spacers covering the package surface to prevent interaction between electromagnetic energy and package. Despite very high heating rate of water, heat was transferred to the product by convection and conduction only. Hence, slow heating rate of product was observed. Melting of package was again observed when the plate temperature rose. Finally, customized grid, made form polyetherimide, was integrated to the container to hold package under water. Grid was manufactured such that they were allowed to touch the package along its length only. Fig. 3.1 provides picture of container and integrated grid. Dimensions of grid for larger container were 40.6 x 0.95 x 2.54 cm^3 and 38.1 x 0.95 x 0.95 cm^3. Dimensions of grid for smaller container were 38.4 x 0.95 x 2.54 cm^3 and 34.3 x 0.95 x 0.95 cm^3.

Based on preliminary experiments, package containing marinated/fresh chicken breast meat was placed in two different containers which were used to cook 1.36 kg and 2.27 kg meats. RO water at 20 °C was added to container till water level reached to the half height of container. Customized grid was inserted on top of the container to prevent package to come up after placing the fiber optic temperature probe of the bottom of package. After the container was filled up with RO water, it was placed between the electrodes. Then electromagnetic field was applied on the package immersed in water. The distance between the electrodes was adjusted such that the anode current flow was 0.7 A. RF oven was turned off when temperature at the center of chicken breast meat reached 74 °C. The temperature was monitored by a fiber optic temperature sensing device (UM14, Universal Multichannel Instrument, Fiso Tech. Inc., Canada) during RF cooking. Packages were opened immediately to get the temperature profile of cooked chicken breast meat. A type K thermocouple was used to measure temperature of cooked chicken breast meat. After measuring the temperature profile of cooked chicken breast meat, it was cooled down to room temperature before measuring quality attributes.

Water Bath Cooking Protocol

Fresh, M20 and M20-G conditioned chicken breast meat were cooked in the water bath (WB). As mentioned above, the main objective of this study was comparison of RF cooking to WB cooking. Since WB cooked samples were considered as control, the experimental design was not a full factorial design. M15 and M15-G conditioned chicken breast meat were not cooked in the WB. Except the fresh chicken breast meat, 2.27 kg packages were also not used in WB cooking due to expectation of similar results between cooking of chicken breast meat in 1.36 kg and 2.27 kg packages. Hence experiments were conducted according to an incomplete randomized block design.

Water bath (Temptronic 100, Thermolyne Corp., Dubuque, IA) with circulating water at 80 °C was used. Packaged marinated/fresh chicken breast meat was placed in the WB. Chicken breast meat was cooked until temperature of the center of chicken breast reached to 74 °C. Temperature profile of cooked chicken breast meat was determined immediately. After measuring the temperature profile of cooked chicken breast meat, it was cooled down to room temperature before conducting quality control analyses.

Sample Storage

Raw and marinated chicken breast meats were stored for 1 and 4 days. One breast from each was packaged and stored at 4 °C. Furthermore, cooked chicken breast meat strips were stored in the cooler for 7 and 30 days. Eighteen chicken breast meat strips of 1.9 cm wide were cut from randomly selected chicken breast meats. One third of cut strips were analyzed at day zero, and the remaining strips were packaged in a plastic pouch (Packall Packaging Brampton, ON, Canada) under vacuum with a vacuum sealer (Henkelman, Hertogenbosch Netherlands). Packaged strips were stored for 7 and 30 days in the cooler at 4 °C. Analyses were conducted when temperature of the strips reached to room temperature. Color, moisture content, pH, expressible moisture and texture analysis were done consecutively.

Moisture Content

Moisture contents of fresh, uncooked marinated and cooked chicken breast meats were determined in duplicate according to the Association of Official Analytical Chemists (AOAC International. 1995). About 3 - 3.5 g samples were placed in appropriate pre-dried aluminum pans (Fisher Scientific, Cat. No. 08-732-101) and were dried in a vacuum oven (Cole-Parmer Instrument Comp., Vermon Hills, IL) for 24h under pressure 80 mmHg at 99 °C.

$$\%\mathrm{Moisture} = (\mathrm{W}_2 - \mathrm{W}_3)/(\mathrm{W}_2 - \mathrm{W}_1) \times 100 \tag{3.1}$$

where, W_1 = weight of dry aluminum pan.

W_2 = weight of wet sample and dry aluminum pan.

W_3 = weight of dry sample and dry aluminum pan.

Moisture content of stored cooked chicken breast meat was determined based on weight and initial moisture content. First the weight of package that was used to pack the cooked chicken breast meat strips and the meat strips were determined, respectively. After storage, meat was removed from package and its weight was measured. Formula given below was used to determine the moisture content.

$$W_{TS} = \left(W_{sample} - W_{pack}\right) \times (100 - \%M_i)/100 \tag{3.2}$$

$$\%M_f = {}^{(W_{store} - W_{TS})}\!/_{W_{store}} \times 100 \tag{3.3}$$

where, W_{store} = weight of cooked chicken breast meat after storage

W_{TS} = weight of calculated total solids

W_{sample} = weight of package and cooked chicken breast meat

W_{pack} = weight of package

$\%M_i$ = Initial moisture content of cooked chicken breast meat

$\%M_f$ = Moisture content of cooked chicken breast meat after storage

pH Value

The pH value of fresh, marinated and cooked chicken breast meats were measured in triplicate according to a direct probe method. A pH meter (Accumet AR15, Fisher Scientific) was used with a flat meat surface probe (Accumet, Cat. No. 13-620-289). Probe of the pH meter was calibrated by using pH 4.00 and pH 7.00 buffer solutions (Fisher Scientific).

Cook Yield

Cook yield was determined based on the original weight (green weight) of fresh chicken breast meat. As described above, cooked meat was cooled down at room temperature and weighed. Cook yield was calculated as follows:

$$\% \text{ Cook yield} = (W_{\text{cooked}} / W_{\text{initial}}) \times 100 \qquad (3.4)$$

Expressible Moisture

Expressible moisture was measured in duplicate according to the filter press method as described by Wierbicki and Deatherage (1958). Samples having fixed diameter and 300 ± 10 mg weight were obtained from fresh, marinated and cooked chicken breast meat. A #12 brass cork borer was used to fix the diameter of samples. A 1.0 kg load cell was allowed to compress the sample that was placed on a pre-weighed Whatmann filter paper (no.1, 9cm) in between two Plexiglass plates for 1min. At the end of the 1 minute, filter paper was weighed to determine the released water from the sample. Expressible moisture was calculated as:

$$\text{Expressible Moisture} = 100 \times (W_{\text{final}} - W_{\text{initial}}) / \text{sample weight} \qquad (3.5)$$

where, W_{final} = weight of filter paper after compression

W_{initial} = initial weight of filter paper

Warner – Bratzler Shear Test

Tenderness of chicken breast meat is an important quality parameter for consumer acceptability level (Cavitt et al. 2005). Warner – Bratzler shear test (WBS) was performed to predict tenderness in the cooked chicken breast meat, as described by Deshpande (2008). Shear force and the work of shearing were determined using a Texture Analyzer (Model TA-XT2i Texture Analyzer; Texture Tech. Corp., Scarsdale, NY) with a 25-kg load cell using a shearing blade (TA 7 – WB blade). As described above, six cooked chicken breast meat strips (1.9 cm wide) were cut to have 2.5 cm long and 2 cm thick samples. Samples were placed on a slotted plate which was installed into a heavy-duty platform (TA 90). Platform was adjustable to allow the blade to pass through the slotted plate. Crosshead speed of the blade was set at 10 mm/s, and the test was triggered by a 0.05 N contact force. Meanwhile preset and posttest speed was set to 5mm/s. Shear force and the work of shearing was calculated as area under the force deformation curve by the texture analyzer. Shear value was reported as mean of six replicates for each cooking.

Color

Color of top surface of cooked chicken breast meat was determined by a chroma meter (Model CR-300 Minolta, Ramsey, NJ). Lightness (L*), a* (redness/greenness), b* (yellowness/blueness), chroma (saturation) and hue angle (H°) were determined. The measurements were reported as mean of six chicken breast meat strips per cooking treatment. A standard white plate was used to calibrate before color measurement of the chicken breast meat.

Statistical Analysis

General Linear Model was used to analyze the data. Comparison between treatments was done by using the least square means (Tukey's test). Statistical analysis was done with Minitab (MINITAB Inc., State College, PA).

Results and Discussion

RF Cooking

Heating rate of product in the RF depends on several parameters such as dielectric properties of product, heating medium, anode and grid current. Anode and grid current are adjusted by changing the distance between upper and lower electrodes. Anode current can be increased by decreasing the distance between electrodes. However, decreasing the distance increases the risk of arcing to occur. In the preliminary study, package was easily melted due to high anode current above 0.7 A. Therefore, cooking was done at that current. Nevertheless, it was difficult to control current when water temperature went above 95 °C. Distance between electrodes was 9 cm at the beginning of the process. Distance was gradually increased till water temperature reached to 97 °C. Then a sharp increase in distance was required to prevent arcing from occuring. However, current was high enough to boil the water. RF generator was turned off for 1 min to cool down the water. Then RF was turned on again. This procedure was done once for the fresh, M20 and M20-G conditioned chicken breast meats. During cooking of M15 and M15-G conditioned chicken breast meat RF was turned off twice. It also observed that considerable water was evaporated during cooking for all experiments.

In several experiments, arcing occurred at the end of the process. Despite developing the RF cooking protocol, arcing occurred either on the container or the grid instead of package. Even though arcing was observed is some experiments, all of the packages that contained the cooked chicken breast meat were free of melting or any sign of burn.

Results showed that RF cooking of chicken breast meat had higher heating rate than WB cooking. Average heating rate of chicken breast meat was 2.67 °C/min during cooking in the RF oven, while it was 1.8 °C/min for WB cooking. Time – temperature graphs for RF and WB cooking of M20 conditioned 1.36 kg chicken breast meat are given in Fig. 3.2 and 3.3.

Cooking Time and Temperature Distribution

National Advisory Committee On Microbiological Criteria For Foods ([Anon] and Nacmcf 2007) recommends cooking poultry products until its internal temperature reaches 74 °C. Therefore, endpoint temperature was selected as 74 °C at the coldest point of the package in both RF oven and WB. Process method significantly affected the cooking time ($p<0.05$). The cooking times of RF and WB process methods are given in Table 3.2. The average time required to cook the 1.36 kg chicken breast meat in the RF was 23.8 min, about 42.4% lower than the time required for WB, 41.3 min. Tang et al. (2005) cooked the turkey breast rolls in the RF oven for 40 min, while it took 150 min to cook it in a thermostatically controlled steam oven at 80 °C. In another study a 79% reduction in cooking time was achieved during cooking of large diameter comminuted meat product (Zhang et al. 2004).

As mass increases by increasing the package size, 2.27 kg chicken breast meat required more time, 32.6 min, to be cooked in the RF oven. It took 57 min to same amount of chicken breast meat in the WB. There was a 42.8% reduction in cooking time with respect to WB cooking ($p<0.05$). Even though WB had circulation of water advantage over RF oven, more time was required to cook the same weight of sample.

Neither marination level nor addition of gum altered the cooking time significantly ($p>0.05$). However, dielectric properties of marinated and fresh chicken breast meat differ. Lee et al. (2008) reported same values for the dielectric constant of fresh and marinated chicken breast meat, 108.5 and 109.7, respectively. Whereas the dielectric loss factor of fresh chicken breast meat was lower than that of marinated chicken breast meat, 415.2 and 967.8, respectively. In contrast, fresh meat had greater penetration depth than marinated meat, 11 m and 8.3 m, respectively. These could be the reason to get the same cooking time for fresh and marinated chicken breast meat.

Mean temperature of the RF cooked chicken breast meat was 79.3 ± 0.4 °C. On the contrary, WB cooked chicken breast meat had better temperature distribution with a 74.9 ± 0.08 °C mean temperature. As heat is generated within the product in the RF oven, uniform temperature distribution was expected. As seen in the Fig. 3.4, temperature of the cooked meat near to the edges and walls of the container was greater than that of the meat in the middle of the container. This is explained by shape, edge or corner effect (Reuter 1993). Edges of the container are usually exposed to more energy than the middle part of the container, as runaway heating occurs. In this study average temperature differential between RF cooked chicken breasts were 5.33 ± 0.4 °C. That was greater than temperature differential between WB cooked chicken breast, 0.9 ± 0.08 °C. In a study, RF cooked muscle beef was reported to have a 10 °C temperature differential within the different areas of muscle (Laycock et al. 2003). Tang et al.

(2005) were able to decrease the temperature differential to 5.3 °C by using circulation of water during RF heating of turkey rolls.

Since RF and WB cooking systems had constant power, increasing mass of the product to be cooked caused increase in the cooking time. This approach (for a particular process in RF heating) was formulated as;

$$E = m \times (\theta_1 - \theta_2) \times c_p/3600 \tag{3.6}$$

where E = absorbed power (kW), m = mass flow rate of product (kg h^{-1}), θ_1= final temperature of product (°C), θ_2 = initial temperature of product (°C), c_p = specific heat of product (kJ kg^{-1} K^{-1}) (Fellows 2000). Thus, the power required (P_r) to cook chicken breast meat can be calculated by:

$$P_r = m \times (\theta_1 - \theta_2) \times c_p/t \tag{3.7}$$

where t = cooking time (s), c_p = 3.521 kJ kg^{-1} K^{-1} (Siripon et al. 2007) and m = mass of product (kg). The power required for the 1.36 kg chicken breast meat was 0.27 kW in the RF cooking. Meanwhile, 0.14 kW power was required in the WB cooking.

Cook Yield

Results for the cook yield are given in Table 3.2. Addition of gum to marinade formula significantly affected the cook yield ($p<0.05$). The highest cook yield was achieved when M15-G and M20-G conditioned chicken breast meats were used. Mean cook yield of M20-G conditioned chicken breast meat was determined as 106.59% due to water binding effect of carrageenan. It was significantly greater than the cook yield of M20 conditioned chicken breast meat, as gum has ability to retain large amount of water. In another study, addition of κ-carrageenan in the low fat pork sausages resulted in lower cook loss (Lyons et al. 1999). Pietrasik (2003) reported that addition of κ-carrageenan improved the water-binding properties of beef gels, so that cook loss was significantly decreased.

Even though marination resulted in significant increase in the cook yield ($p<0.05$), the marination level did not significantly affect the cook yield ($p>0.05$). In fact, marinated chicken breast meats contained the same percentage of STPP and salt regardless of their marination level. Besides marination level, both cooking methods, RF and WB cooking, had no significant effect on the cook yield ($p>0.05$). Like this study, cook yield of RF cooked and steam cooked turkey rolls was statistically same (Tang et al. 2005). In addition, cook yield of steam and RF cooked luncheon rolls were also reported as statistically same (Zhang et al. 2004). However, Laycock et al. (2003) reported higher cook yield for RF cooked samples than that of WB cooked samples.

Moisture Content

Total moisture content of the marinated chicken breast meat was higher than that of fresh chicken breast meat (Table 3.3). It was observed that moisture content of the raw chicken breast meat varied by the lot. To eliminate this error, moisture content of fresh chicken breast meat was subtracted from that of marinated chicken breast meat and the differences were statistically analyzed. Moisture content of fresh chicken breast meat was determined to be 76.12%. Moisture content of fresh chicken breast meat determined by AOAC method was reported as 76.60% and 76.35% in two different studies (Barbanti and Pasquini 2005; Qiao et al. 2001). Marination resulted in significant increase in the moisture content of chicken breast meat except M15-G conditions ($p>0.05$). The highest increase in moisture content was observed in M20-G conditions ($p<0.05$). Marination level did not significantly affect the moisture content of breast meats. The effect of gum addition on moisture content of marinated chicken breast meat was not clear. Insolubility of carrageenan at low temperature might have caused the lack of clarity, but ι-carrageenan can swell in cold water. Although error term was statistically considered during data analysis, sampling and experimental errors might be the reason to get the same moisture content in fresh and M15-G treatment.

Moisture content of RF and WB cooked chicken breast meat is given in Table 3.4. RF and WB cooking didn't show any significant effect on moisture content of cooked meats ($p>0.05$). Gum and marination level significantly increased the moisture content of cooked chicken breast meat. Although there was no significant difference between moisture content of cooked meat in M15-G and M20-G conditions ($p>0.05$), M20 conditioned cooked meats had significantly greater moisture content than M15 conditioned cooked meats. Addition of gum significantly increased the moisture content of cooked meat at the same marination level ($p<0.05$). In fact, gelatinization and stability of carrageenan structure were established during cooling period after heating. Gelatinization occurs due to hydrogen bonding leading to the development of double helix structures (Norziah et al. 2006).

Zheng et al. (1999) reported moisture content of cooked fresh and marinated chicken breast meat as 71.6% and 75.1%, respectively. In this study, mean moisture content of cooked fresh and marinated chicken breast meat was determined as 69.57% and 73.78%, respectively.

Expressible Moisture

Expressible moisture values are given in Table 3.5 for fresh and marinated chicken breast meat. According to the results, all marinated chicken breast meat had significantly lower expressible moisture value than fresh chicken breast meat ($p<0.05$). This result shows that free water (unbound water) of the raw chicken breast meat was retained by meat protein structure, gum or their interaction due to marination and gum addition. Addition of gum at the same marination level did not affect the expressible moisture significantly ($p>0.05$). Even though ι-carrageenan is insoluble in cold water, it swells during tumbling process. Nevertheless, swelling of gum did not result in low expressible moisture value at the same marination level. In addition to gum addition, marination level did not affect the expressible moisture significantly ($p>0.05$). It might be related to having same concentration levels of salt and STPP in the final product in both, 15% and 20% pick-up marinated chicken breast meat.

Expressible moisture values of cooked chicken breast meat are given in Table 3.6. Results showed that there is not any significant difference between expressible moisture content values ($p>0.05$). RF and WB cooking did not affect the expressible moisture significantly, which is similar to the results given for cooking of comminuted pork meat product (Brunton et al. 2005). In another study, however, RF cooked ground beef and whole muscle meat products had better water holding capacity than WB cooked ground beef and whole muscle meat products (Laycock et al. 2003). Furthermore, Zhang et al. (2004) concluded that water holding capacity of RF cooked sample was better than that of steam cooked samples. Expressible moisture value results were the same for all conditions of chicken breast meat. In other words, neither marination level nor gum addition to the marinade significantly affected the expressible moisture of cooked meat. In their study, Filipi and Lee (1998) expressed the same conclusion that pre-activated ι-carrageenan had no significant effect on expressible moisture of surimi gel, however, they indicated that dry ι-carrageenan significantly lowers the expressible moisture. In another study, expressible moisture values were the same for fresh and marinated chicken breast meat with different marinade formulations (Zheng et al. 2001).

pH Value

The pH values of raw and marinated chicken breast meat are presented in Table 3.7. The pH value of raw chicken breast meat was varied by each lot. Storage of some raw chicken breast meat for 1 day prior to cook or unequal aging of chicken breast meat at the processing plant might be the reasons for that variation. To neutralize that error term, pH difference between marinated and raw chicken breast meat was analyzed. As pH was determined by direct probe method, inaccuracy of the flat meat surface probe might also account for the difference in pH values.

Mean pH value for raw chicken breast meat was determined as 5.98. It is lower than 6.12 and greater than 5.81 when compared to the reported pH value for raw chicken breast meat in other studies (Zheng et al. 1999; Qiao et al. 2002). Results showed that the marinated chicken breast meat at 20% pick up (M20 and M20-G) had significantly greater pH value than the raw meat ($p<0.05$). However, there was no significant difference in pH values of 15% pick-up marinated (M15 and M15-G) and raw chicken breast meat. Despite the fact that actual aim of marination is to shift the pH toward basic pH, results did not show obvious rise of the pH value of chicken breast meat after marination. Mean pH value for marinated chicken breast meat was determined as 6.02. It was very close to the 6.03 reported by Qiao et al. (2002), and lower than 6.81 reported by Zheng et al. (1999). Addition of gum did not significantly affect the pH value at the same marination level ($p>0.05$). Since semi refined ι-carrageenan has almost neutral pH, those results were expected.

Table 3.8 shows the pH value of cooked chicken breast meat. RF and WB cooking methods did not significantly affect the pH value of cooked chicken breast meat ($p>0.05$). All marinated chicken breast meats had significantly greater pH value than the fresh chicken breast meat after cooking ($p>0.05$). Mean pH value for cooked marinated chicken breast meat was determined as 6.24. Qiao et al. (2002) reported pH of 6.31 for cooked marinated chicken breast meat. Marination level and addition of gum didn't significantly affect the pH value of cooked marinated chicken breast meat ($p>0.05$).

Warner – Bratzler Shear Test

Warner – Bratzler shear force values of cooked chicken breast meat are given in Table 3.9. Results showed that M15-G and M20-G conditioned chicken breast meat had the lowest shear values. Addition of gum significantly decreases the shear value of cooked chicken breast meat at same marinated level ($p<0.05$). Moisture-binding ability of ι-carrageenan improves the succulence of chicken breast meat. Marinated chicken breast meat had significantly lower shear value than fresh chicken breast meat ($p<0.05$), but marination level didn't significantly affect the shear value ($p>0.05$). Water binding capacity of chicken breast meat is improved by salt and phosphate. Concentration of the salt and phosphate in the M15 and M20 conditioned chicken breast meat were same. That could be the reason to have same shear value for different marination levels. Qiao et al. (2002) reported that shear force value was not significantly correlated to the marination pick up level.

Results showed that cooking method didn't affect the shear value significantly ($p>0.05$). Tang et al. (2005) also indicated no significant difference between texture profile of RF and steam cooked turkey rolls ($p>0.05$). In contrast, according to the research of Zhang et al. (2006), RF cooked leg and shoulder ham had higher Warner-Bratzler shear values than their steam cooked counterparts. Furthermore some parameters such as and were significantly different when texture profile of RF and steam cooked samples were found in previous studies (Laycock et al. 2003; Zhang et al. 2004).

Same interpretations can be used for work of shear. Similar to the shear force, M15-G and M20-G conditioned chicken breast meats had the lowest value for work of shear ($p<0.05$). Fresh chicken breasts had the highest value for work of shear, in other words it had the lowest water retention among all chicken breast meats ($p<0.05$). RF and WB cooking methods didn't significantly affect the work of shear values ($p>0.05$).

Color

Color of the cooked chicken breast meat might be affected by cooking methods and addition of gum. As the non-uniform temperature distribution was observed in the RF cooked samples (Figure 3.1), color parameters of them might differ when compared to that of WB cooked samples. Moreover, addition of gum to the marinade changed its color. Hence, effect of gum on cooked chicken breast meat was also discussed. Color measurement results including the effect of marination are shown in Appendix B.

Color measurements are given in Table 3.10 for two different cooking methods. Redness and saturation of the cooked chicken breast meat significantly differs with respect to cooking methods ($p<0.05$). RF and WB cooked chicken breast meat had same lightness, yellowness and hue values ($p>0.05$). RF cooked chicken breast meats had lower redness and saturation value than their WB cooked counterparts ($p<0.05$). Non-uniform heating of chicken breast meat in the RF was the reason to have lower redness and saturation value. Those results were in agreement with those of Tang et al. (2005) for turkey rolls. They indicated that RF cooked turkey rolls had the same lightness and yellowness value as steam cooked rolls. On the other hand, lower redness values were observed for RF cooked turkey rolls. Laycock et al. (2003) reported that RF and WB cooked ground and comminuted beef and whole muscle had same lightness and redness values. In another study, no significant difference between L*, a*, b*, saturation and hue angle values of steam, WB and RF cooked comminuted pork meat products was stated (Brunton et al. 2005). Barbut et al. (2005) reported the L* value of the WB cooked chicken breast meat as 79.73. In another study, L*, a* and b* values of the steam cooked chicken breast meat were reported as 77.16, 1.69 and 10.14 respectively (Qiao et al. 2002). Whereas, Young and Lyon (1997) reported L*, a* and b* values of the WB cooked chicken breast meat were reported as 78.7, 2.55 and 15.7 respectively.

As addition of gum changes color of marinade, it might affect the L*, b* and saturation values of the cooked meat. Color measurement results of gum added and control meat samples are given in Table 3.11. Cooked chicken breast meat containing gum showed significantly lower yellowness and saturation value when compared to chicken breast meat which did not contain any gum compound ($p<0.05$). Moreover addition of gum to the chicken breast meat did not affect the lightness, redness and hue value significantly ($p>0.05$).

Conclusions

RF cooking of packaged fresh and marinated chicken breast meat was successfully done in the HDPE containers with the integration of the grid. Packages were immersed in the RO water until end of the process, as it was impossible to cook chicken breasts in air due to arcing. Having high heating rate in the RF oven, chicken breast meat was cooked in less time when compared to WB cooking. It took almost 24 min and 33 min to cook 1.36 kg and 2.27 kg chicken breast meat, respectively, in the RF oven, comparing it to 41.3 min and 57 min in the WB. 42.4% and 42.8% reductions in cooking time were observed. Even though rapid cooking was observed in RF cooking, temperature distribution of cooked meat was not as uniform as that of WB cooking. Edge effect and thermal runaway were the main reasons for the observed variability in mean temperature of the RF cooked breasts as 79.3 °C even though the target end point temperature was 74 °C. Mean temperature of the WB cooked breasts was 74.9 °C. RF cooking resulted in 5.33 °C average temperature differential, whereas, it was 0.9 °C in WB cooking.

Instrumental quality analysis showed that there were no significant difference between RF and WB cooked products with regard to cook yield, moisture content, pH, expressible moisture, shear value. Color measurements showed that L*, b*, hue values of the RF and WB cooked breast were statistically same. However, RF cooked breasts had lower a* and saturation value, possibly due to non-uniform temperature distribution. Marination and addition of ι-carrageenan had positive effect on cook yield, moisture content, and shear value of cooked chicken breasts. Gum added breasts had the lowest shear value, meaning the most tender meat. The effect of marination and gum addition on the pH value of raw and cooked chicken breast meat could not be observed clearly. However, their effects on expressible moisture were insignificant. RF oven can be used to cook packaged chicken breast meat in the industry because of its economy and time saving properties.

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Table 3.1: Marinade composition and pick-up

	Treatment symbol				
	Fresh	M15	M15-G	M20	M20-G
Salt (%)	-	7.6	7.6	6	6
STPP (%)	-	2.3	2.3	1.8	1.8
Carrageenan (%)	-	-	1.9	-	1.5
Pick-up (%)	-	15	15	20	20

Table 3.2: Cooking time and cook yield of RF and WB cooked fresh and marinated chicken breast meat at different marination level with and without gum

		Cook Yield (%)	Cooking Time (min)	
			1.36kg	2.27kg
RF[1]	Fresh	$76.5^{a} \pm 2.3$	$20.5^{a} \pm 0.7$	$28.75^{a} \pm 1.1$
	M15	$92.5^{b} \pm 4.4$	$27.5^{a} \pm 0.7$	$36.75^{a} \pm 7.4$
	M15-G	$101.72^{c} \pm 1.6$	$24.5^{a} \pm 0.7$	$30^{a} \pm 1.4$
	M20	$95.98^{b} \pm 1.4$	$23.5^{a} \pm 0.7$	$34^{a} \pm 1.4$
	M20-G	$105.73^{c} \pm 2.9$	$23^{a} \pm 1.4$	$33.5^{a} \pm 3.5$
WB[2]	Fresh	$77.48^{a} \pm 1.3$	$41^{b} \pm 1.4$	$57^{b} \pm 0.7$
	M20	$99.45^{b} \pm 0.2$	$41^{b} \pm 0.0$	n/a
	M20-G	$107.45^{c} \pm 0.6$	$42^{b} \pm 1.4$	n/a

(Data shown is mean ± standard deviation)
Different letters in the same column show significant difference ($p<0.05$)

[1] RF stands for radio-frequency cooking

[2] WB stands for water bath cooking

Table 3.3: Total moisture of fresh meat and marinated meat at different marination level with and without gum

	Raw meat moisture (%)				Marinated meat moisture (%)				ΔMC[1]
	Day 0	Day 1	Day 4	Mean	Day 0	Day 1	Day 4	Mean	Mean
Fresh	75.85 ± 0.4	75.50 ± 0.1	75.24 ± 0.5	75.61 ± 0.4	75.85 ± 0.4	75.50 ± 0.1	75.24 ± 0.5	75.61 ± 0.4	0.00^{a} ± 0.0
M15	75.50 ± 0.1	75.43 ± 0.8	74.84 ± 1.3	75.32 ± 0.7	76.29 ± 0.7	75.94 ± 0.01	76.12 ± 0.4	76.16 ± 0.5	0.84^{bc} ± 0.8
M15-G	76.20 ± 0.3	75.97 ± 0.2	75.73 ± 0.1	76.02 ± 0.3	76.35 ± 1.2	75.90 ± 1.1	75.90 ± 1.1	76.13 ± 0.2	0.11^{ab} ± 0.2
M20	76.42 ± 0.5	75.42 ± 0.3	75.65 ± 0.3	75.98 ± 0.6	77.42 ± 0.8	76.87 ± 0.7	76.68 ± 1.2	77.10 ± 0.9	1.12^{c} ± 1.2
M20-G	76.62 ± 0.6	76.09 ± 0.6	75.95 ± 0.4	76.32 ± 0.6	79.12 ± 1.6	78.73 ± 1.1	78.52 ± 1.2	78.87 ± 1.3	2.55^{d} ± 1.0

(Data shown is mean ± standard deviation)

Different letters in the same column shows significant difference ($p<0.05$)

[1] ΔMC = Moisture content of marinated chicken breast meat – Moisture content of raw chicken breast meat

Table 3.4: Total moisture of RF and WB cooked chicken breast meat at different marination level with and without gum

		Moisture Content (%)			
		Day 0	Day 7	Day 30	Mean
RF	Fresh	70.11 ± 1.4	69.39 ± 0.7	69.12 ± 0.8	69.68^{a} ± 1.2
	M15	72.25 ± 0.9	71.17 ± 0.6	71.04 ± 1.0	71.68^{b} ± 1.0
	M15-G	74.84 ± 1.4	73.87 ± 1.0	73.86 ± 1.3	74.35^{cd} ± 1.4
	M20	73.99 ± 1.5	72.87 ± 1.5	72.97 ± 1.4	73.45^{c} ± 1.5
	M20-G	75.20 ± 1.5	74.32 ± 1.5	74.32 ± 1.4	74.76^{d} ± 1.5
WB	Fresh	69.95 ± 1.0	68.93 ± 0.5	69.04 ± 0.5	69.46^{a} ± 0.9
	M20	74.65 ± 0.5	73.71 ± 0.3	73.41 ± 0.2	74.11^{c} ± 0.7
	M20-G	75.61 ± 1.7	74.55 ± 1.8	74.48 ± 1.6	75.06^{d} ± 1.6

(Data shown is mean ± standard deviation)
Different letters in the same column shows significant difference ($p<0.05$)

Table 3.5: Expressible moisture (EM) of fresh meat and marinated meat at different marination level with and without gum

	Raw EM (%)				Marinated EM (%)				ΔEM[1]
	Day 0	Day 1	Day 4	Mean	Day 0	Day 1	Day 4	Mean	
Fresh	16.27 ± 3.0	14.91 ± 1.9	15.94 ± 1.3	15.71 ± 2.2	16.27 ± 3.0	14.91 ± 1.9	15.94 ± 1.3	15.71 ± 2.2	0.0^{a} ± 0.0
M15	14.80 ± 2.4	13.06 ± 0.5	14.36 ± 2.5	14.07 ± 2.1	13.18 ± 2.1	10.71 ± 3.6	10.29 ± 2.3	11.39 ± 3.0	-2.68^{b} ± 3.3
M15-G	14.91 ± 0.5	16.65 ± 0.5	14.36 ± 1.3	15.37 ± 1.3	11.40 ± 1.2	10.72 ± 1.7	10.78 ± 2.1	10.96 ± 1.7	-4.41^{b} ± 1.9
M20	12.98 ± 1.0	14.68 ± 0.8	16.44 ± 1.3	14.70 ± 1.8	11.86 ± 2.5	11.48 ± 2.1	11.39 ± 3.6	11.57 ± 2.4	-3.13^{b} ± 3.3
M20-G	16.66 ± 0.5	15.87 ± 1.7	17.65 ± 1.3	16.73 ± 2.3	12.04 ± 1.6	14.06 ± 1.8	12.04 ± 2.5	12.71 ± 2.2	-4.01^{b} ± 2.9

(Data shown is mean ± standard deviation)

Different letters in the same column shows significant difference ($p<0.05$)

[1] ΔEM = Expressible moisture of marinated chicken breast meat – Expressible moisture of raw chicken breast meat

Table 3.6: Expressible moisture of RF and WB cooked chicken breast meat at different marination level with and without gum

		Expressible Moisture (%)			
		Day 0	Day 7	Day 30	Mean
RF	Fresh	12.17 ± 1.4	8.92 ± 3.2	10.44 ± 1.9	10.51 ± 2.6
	M15	13.64 ± 2.4	8.56 ± 1.9	10.22 ± 3.6	10.80 ± 3.4
	M15-G	10.45 ± 1.8	11.30 ± 4.2	10.76 ± 1.7	10.84 ± 2.7
	M20	11.89 ± 3.3	10.30 ± 4.3	11.30 ± 3.2	11.16 ± 3.5
	M20-G	11.90 ± 1.9	10.65 ± 3.4	11.37 ± 3.0	11.31 ± 2.8
WB	Fresh	11.69 ± 1.5	10.56 ± 1.6	11.14 ± 2.3	11.13 ± 1.9
	M20	12.95 ± 3.9	11.02 ± 4.5	9.66 ± 1.9	11.21 ± 3.6
	M20-G	13.59 ± 2.6	11.76 ± 1.8	11.88 ± 0.8	12.41 ± 1.9

(Data shown is mean ± standard deviation)

No significant difference between % Expressible Moisture values ($p>0.05$)

Table 3.7: pH of fresh meat and marinated meat at different marination level with and without gum

	Raw				Marinated				ΔpH[1]
	Day 0	Day 1	Day 4	Mean	Day 0	Day 1	Day 4	Mean	Mean
Fresh	5.87 ± 0.05	5.85 ± 0.06	5.80 ± 0.06	5.84 ± 0.07	5.87 ± 0.05	5.85 ± 0.06	5.80 ± 0.06	5.84 ± 0.07	0.00^{a} ± 0.00
M15	6.03 ± 0.09	5.90 ± 0.13	5.96 ± 0.15	5.96 ± 0.14	6.00 ± 0.03	5.99 ± 0.05	6.04 ± 0.16	6.04 ± 0.10	0.05^{abc} ± 0.10
M15-G	6.03 ± 0.06	6.03 ± 0.05	6.00 ± 0.07	6.02 ± 0.06	6.06 ± 0.09	6.06 ± 0.10	6.00 ± 0.12	6.01 ± 0.11	0.02^{ab} ± 0.10
M20	5.96 ± 0.07	5.88 ± 0.09	5.92 ± 0.04	5.92 ± 0.08	5.96 ± 0.05	6.05 ± 0.06	5.97 ± 0.06	6.02 ± 0.07	0.10^{c} ± 0.11
M20-G	6.03 ± 0.05	5.92 ± 0.10	5.98 ± 0.07	5.97 ± 0.09	6.07 ± 0.06	6.03 ± 0.04	6.07 ± 0.05	6.05 ± 0.09	0.07^{bc} ± 0.09

(Data shown is mean ± standard deviation)

Different letters in the same column shows significant difference ($p<0.05$)

[1] ΔpH = pH of marinated chicken breast meat – pH of raw chicken breast meat

Table 3.8: pH of RF and WB cooked chicken breast meat at different marination level with and without gum

		pH			
		Day 0	Day 7	Day 30	Mean
RF	Fresh	6.18 ± 0.05	6.14 ± 0.05	6.08 ± 0.06	6.13^{a} ± 0.06
	M15	6.28 ± 0.06	6. 24 ± 0.05	6.09 ± 0.05	6.20^{bc} ± 0.10
	M15-G	6.26 ± 0.05	6.21 ± 0.03	6.17 ± 0.03	6.21^{bc} ± 0.05
	M20	6.20 ± 0.08	6.21 ± 0.05	6.21 ± 0.06	6.21^{c} ± 0.06
	M20-G	6.27 ± 0.04	6.19 ± 0.03	6.25 ± 0.04	6.24^{b} ± 0.05
WB	Fresh	6.17 ± 0.06	6.14 ± 0.05	6.08 ± 0.06	6.13^{a} ± 0.07
	M20	6.17 ± 0.04	6.22 ± 0.03	6.17 ± 0.04	6.19^{c} ± 0.04
	M20-G	6.28 ± 0.02	6.22 ± 0.03	6.24 ± 0.02	6.24^{b} ± 0.03

(Data shown is mean ± standard deviation)
Different letters in the same column shows significant difference ($p<0.05$)

Table 3.9: Shear and work of shear of RF cooked and WB cooked chicken breast meat at different marination level with and without gum

		Shear Value (N)				Work of shear (N.m)			
		Day 0	Day 7	Day 30	Mean	Day 0	Day 7	Day 30	Mean
RF	Fresh	21.54 ± 8.9	27.53 ± 10.7	28.04 ± 15.4	25.78^{a} ± 12.3	43.16 ± 18.6	52.71 ± 20.8	52.25 ± 31.6	49.48^{a} ± 24.6
	M15	15.32 ± 5.4	18.78 ± 8.9	19.20 ± 7.8	17.79^{b} ± 7.6	28.54 ± 9.9	37.53 ± 18.2	39.68 ± 14.6	35.31^{b} ± 15.3
	M15-G	11.55 ± 1.8	12.62 ± 2.3	12.60 ± 3.3	12.25^{c} ± 2.6	23.88 ± 3.3	24.84 ± 3.8	26.26 ± 5.6	24.99^{c} ± 4.4
	20	17.52 ± 7.4	21.28 ± 11.1	25.97 ± 16.2	21.37^{b} ± 12.2	31.78 ± 13.7	41.32 ± 18.7	49.68 ± 28.4	40.47^{b} ± 21.8
	M20-G	11.30 ± 1.7	11.99 ± 2.7	12.64 ± 2.6	11.96^{c} ± 2.4	23.45 ± 3.6	23.98 ± 4.6	25.32 ± 5.5	24.23^{c} ± 4.6
WB	Fresh	23.59 ± 6.6	27.19 ± 13.9	29.71 ± 19.8	26.94^{a} ± 14.8	44.35 ± 12.9	53.02 ± 26.5	57.20 ± 37.9	51.76^{a} ± 28.3
	M20	21.55 ± 10.2	18.60 ± 6.3	24.13 ± 12.1	21.42^{b} ± 9.8	40.47 ± 20.5	37.25 ± 10.7	45.52 ± 18.7	41.10^{b} ± 16.9
	M20-G	11.08 ± 2.5	10.52 ± 2.1	10.88 ± 1.8	10.82^{c} ± 2.1	22.96 ± 4.6	21.79 ± 3.8	23.64 ± 3.7	22.75^{c} ± 4.1

(Data shown is mean ± standard deviation)
Different letters in the same column shows significant difference ($p<0.05$)

Table 3.10: L* (lightness), a* (redness), b* (yellowness), chroma (saturation) and hue value of the RF and WB cooked chicken breast meat (fresh and marinated without gum)

	L*	a*	b*	Saturation	Hue
RF	79.31 ± 1.4	0.90^a ± 0.7	12.31 ± 1.2	12.35 ± 1.4	85.77^a ± 3.1
WB	79.65 ± 1.3	1.49^b ± 0.6	12.23 ± 1.4	12.33 ± 1.4	83.03^b ± 2.8

(Data shown is mean ± standard deviation)

Different letters in the same column shows significant difference ($p<0.05$)

Table 3.11: Effect of gum addition on the color of the RF and WB cooked chicken breast meat

		L*	a*	b*	Saturation	Hue
RF	Gum	79.00 ± 1.8	0.68 ± 0.7	10.47^{a} ± 1.2	10.51^{a} ± 1.1	86.13 ± 4.2
	Control	79.31 ± 1.4	0.90 ± 0.7	12.31^{b} ± 1.2	12.35^{b} ± 1.4	85.77 ± 3.1
WB	Gum	79.44 ± 1.7	1.65 ± 0.6	9.57^{a} ± 0.7	9.72^{a} ± 0.7	80.21 ± 3.5
	Control	79.65 ± 1.3	1.49 ± 0.6	12.23^{b} ± 1.4	12.33^{b} ± 1.4	83.03 ± 2.8

(Data shown is mean ± standard deviation)
Different letters in the same column in the same cooking method shows significant difference ($p<0.05$)

Figure 3.1 Container with grid in the RF oven

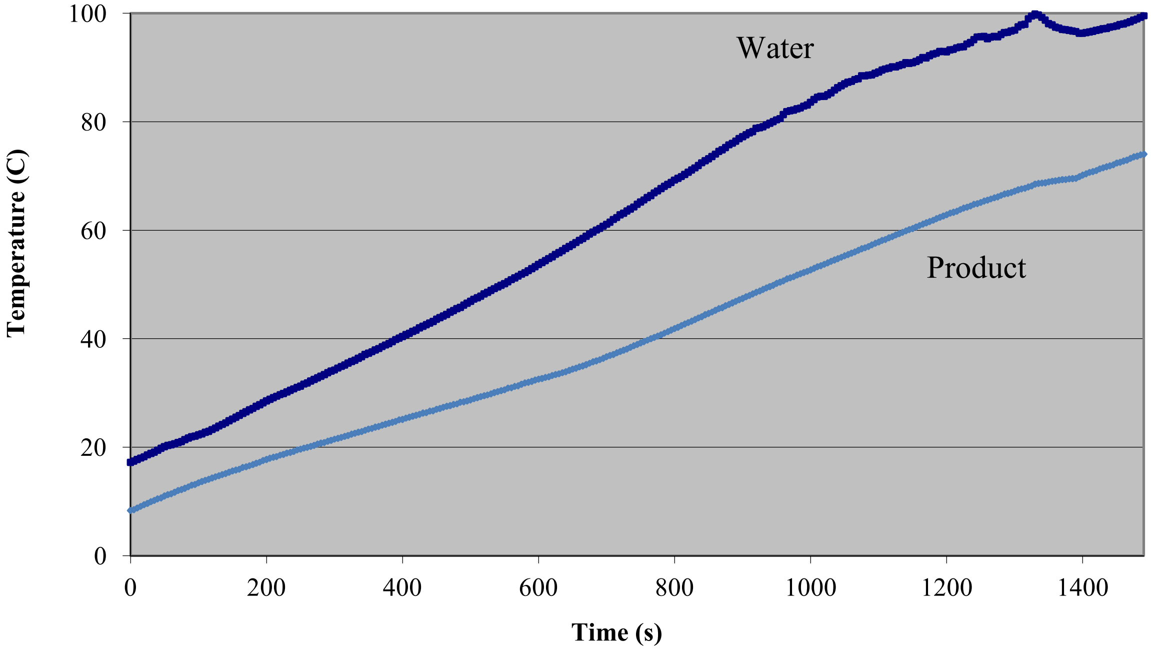

Figure 3.2: Time - temperature graph for RF cooking of 1.36 kg 20% pick-up marinated chicken breast meat

20% pick-up marinated chicken breast meat dielectric properties at 27 MHz at 20 °C (Lee et al. 2008)
$\varepsilon' = 111.5$
$\varepsilon'' = 919$

20% pick-up marinated chicken breast meat dielectric properties at 27 MHz at 60 °C (Lee et al. 2008)
$\varepsilon' = 135.1$
$\varepsilon'' = 1686$

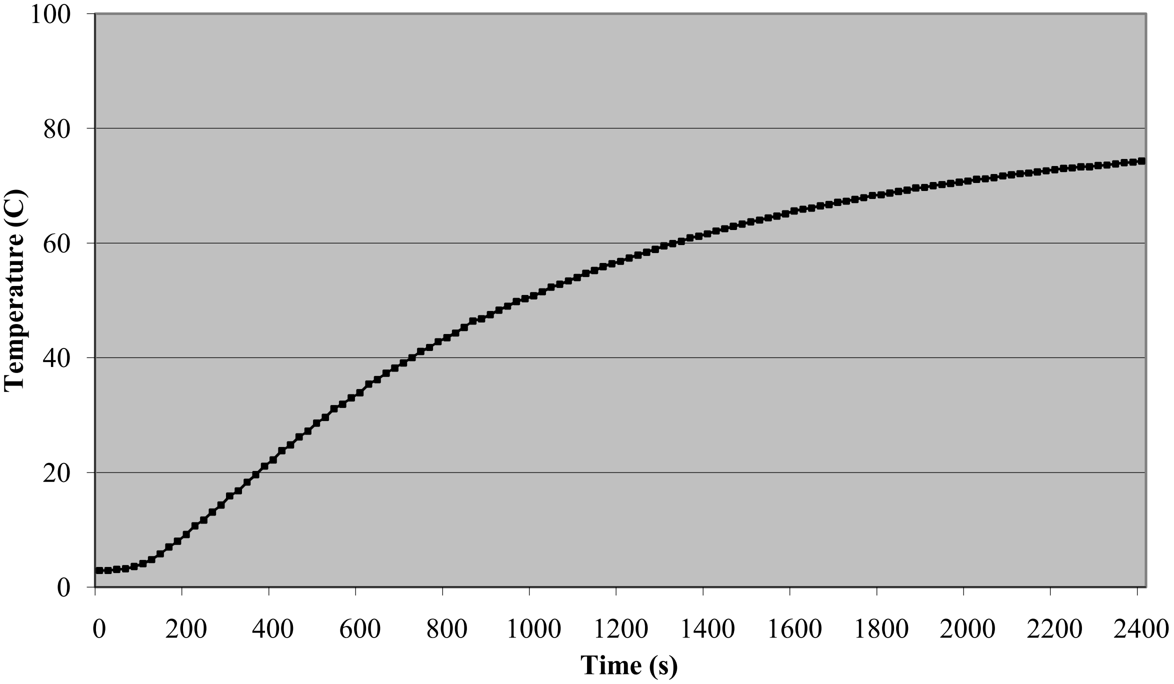

Figure 3.3: Time - temperature graph for WB cooking of 1.36 kg 20% pick-up marinated chicken breast meat

Fig.3.4 Temperature distribution of RF cooked 1.36 kg 20% pick-up marinated chicken breast meat with ι-carrageenan
Temperatures are given in °C.

CHAPTER 4

CONCLUSION

RF cooking of packaged fresh and marinated chicken breast meat was successfully done in the HDPE containers with the integration of grid. Packages were immersed in RO water in order to prevent melting due to arcing. RF cooking method considerably reduced the cooking time of chicken breast meat by 42.4% with respect to WB cooking. On the contrary, RF cooked breast did not result in uniform heating as expected due to thermal runaway and edge effect. Mean temperature of the RF cooked breasts (79.3 °C) was greater than that of WB cooked breasts (74.9 °C) even though the target end point temperature was 74 °C. RF cooking resulted in 5.33 °C average temperature differential, whereas it was 0.9 °C in WB cooking.

RF cooked meat had the acceptable quality parameters when compared to WB cooked breasts except the some color parameters (a* and saturation value). Cook yield, moisture content, pH, expressible moisture and shear values of the both RF and WB cooked meat had statistically same values. Differences in a* and saturation values were due to non-uniform heating in the RF oven.

Like many other studies on marination, it was also concluded that marination improved the quality parameters of the cooked chicken breast meat. Addition of ι-carrageenan also improved the quality of cooked chicken breast meat; nevertheless, different levels of added ι-carrageenan should be studied with regard to quality of cooked breasts. Marination and addition of ι-carrageenan had positive effect on cook yield, moisture content, and shear value of cooked breasts. The effect of marination and gum addition on the pH value of raw and cooked chicken breast meat could not be observed clearly. However, their effects on expressible moisture were insignificant.

This study showed that RF cooking of packaged chicken breast meat was a promising process that can be used in the food industry. However, future work will be needed to improve temperature distribution throughout the package. Moreover sensory evaluation is essential and should be conducted to investigate the acceptability of product.

APPENDICES

A. Experimental Design

Parameters:

Raw – 0% pick-up

15% - 15% pick-up

20% - 20% pick-up

Gum (G) – Marinade contains ι-carrageenan.

No Gum (NG) – Marinade does not contain ι-carrageenan.

1.36 kg – Packaged chicken breast meat in 1.36 kg.

2.27 kg – Packaged chicken breast meat in 2.27 kg.

WB – Water bath cooking of packaged chicken breast meat

RF – Radio-frequency cooking of packaged chicken breast meat

I – First experiment

II – Second experiment

Experiments

1) Batch 1a - Raw (0%) - 1.36 kg – WB - I

2) Batch 2a - Raw (0%) - 1.36 kg – WB - II

3) Batch 1a - Raw (0%) - 1.36 kg – RF – I

4) Batch 2a - Raw (0%) - 1.36 kg – RF – II

5) Batch 1b - Raw (0%) - 2.27 kg – WB – I

6) Batch 2b - Raw (0%) - 2.27 kg – WB – II

7) Batch 1b - Raw (0%) - 2.27 kg – RF – I

8) Batch 2b - Raw (0%) - 2.27 kg – RF – II

9) Batch 3a - 15% - Gum – 1.36 kg – RF - I

10) Batch 4a - 15% - Gum – 1.36 kg – RF – II

11) Batch 3a - 15% - Gum – 2.27 kg – RF - I

12) Batch 4a - 15% - Gum – 2.27 kg – RF – II

13) Batch 5a - 15% - No Gum – 1.36 kg – RF - I

14) Batch 6a - 15% - No Gum – 1.36 kg – RF – II

15) Batch 5a - 15% - No Gum – 2.27 kg – RF - I

16) Batch 6a - 15% - No Gum – 2.27 kg – RF – II

17) Batch 3b - 20% - Gum – 1.36 kg – WB - I

18) Batch 4b - 20% - Gum – 1.36 kg – WB – II

19) Batch 3b - 20% - Gum – 1.36 kg – RF - I

20) Batch 4b - 20% - Gum – 1.36 kg – RF – II

21) Batch 3b - 20% - Gum – 2.27 kg – RF - I

22) Batch 4b - 20% - Gum – 2.27 kg – RF – II

23) Batch 5b - 20% - No Gum – 1.36 kg – WB - I

24) Batch 6b - 20% - No Gum – 1.36 kg – WB – II

25) Batch 5b - 20% - No Gum – 1.36 kg – RF - I

26) Batch 6b - 20% - No Gum – 1.36 kg – RF – II

27) Batch 5b - 20% - No Gum – 2.27 kg – RF - I

28) Batch 6b - 20% - No Gum – 2.27 kg – RF – II

B. Color measurements

Table B.1 L* (lightness), a* (redness), b* (yellowness), chroma (saturation) and hue value of the RF and WB cooked fresh and marinated chicken breast meat at different marination level with and without gum

		L*	a*	b*	Chroma	Hue
RF	Fresh	79.94 ± 1.3	0.62 ± 0.6	12.71 ± 1.2	12.74 ± 1.2	87.12 ± 2.9
	M15	78.79 ± 1.2	0.85 ± 0.6	11.96 ± 1.2	11.98 ± 1.2	85.88 ± 2.8
	M15-G	78.57 ± 1.4	0.69 ± 0.8	10.65 ± 1.1	10.69 ± 1.1	86.18 ± 4.2
	M20	79.25 ± 1.4	1.22 ± 0.6	12.28 ± 1.7	12.36 ± 1.7	84.29 ± 3.1
	M20-G	79.4 ± 2.0	0.67 ± 0.7	10.30 ± 1.2	12.34 ± 1.2	86.09 ± 4.2
WB	Fresh	79.80 ± 1.4	1.40 ± 0.6	12.77 ± 1.1	12.85 ± 1.1	83.82 ± 2.5
	M20	79.36 ± 0.9	1.67 ± 0.5	11.15 ± 1.4	11.29 ± 1.3	81.45 ± 2.9
	M20-G	79.44 ± 1.7	1.65 ± 0.6	9.57 ± 0.7	9.72 ± 0.7	80.21 ± 3.5

(Data shown is mean ± standard deviation)

C. Cook Time and Cook Yield Data

Table C.1 Raw data of cook time and cook yield of RF and WB cooked chicken breast meat

		Cook Yield		Cooking Time (min)	
				1.36kg	2.27kg
RF	Fresh	79.6	74.6	21	28
		77	74.8	20	29.5
	M15	93.8	98	27	31.5
		90.4	87.8	28	42
	M15-G	99.5	102.9	25	29
		101.6	102.9	24	31
	M20	94	96.2	24	35
		97.2	96.5	23	33
	M20-G	102.6	103.9	22	36
		108.2	108.2	24	31
WB	Fresh	79.3	77.2	40	56.5
		77	76.4	42	57.5
	M20	99.3	n/a	41	n/a
		99.6		41	
	M20-G	107.9	n/a	43	n/a
		107		41	

(Data shown is mean ± standard deviation)