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Ph.D in Food Engineering

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UNIVERSITY OF GAZİANTEP

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EFFECTS OF HYBRID (ULTRASOUND, OHMIC AND INFRARED) TREATMENTS ON THE QUALITY CHARACTERISTICS OF MEAT

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Supervisor

Prof. Dr. Hüseyin BOZKURT

by

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Anıl UZUN ÖZCAN

ABSTRACT

EFFECTS OF HYBRID (ULTRASOUND, OHMIC AND INFRARED) TREATMENTS ON THE QUALITY CHARACTERISTICS OF MEAT

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In this study, effect of hybrid cooking system which is the consecutive application of ultrasound (10, 20 and 30 min.), ohmic (40, 55 and 70 V) and infrared treatments (325, 375 and 425 °F) on quality characteristics of meat were investigated. Hybrid cooking system was also compared with ohmic cooking alone, infrared cooking alone, ultrasound – ohmic, ohmic – infrared treatments. The effect of system variables on moisture content, pH, color, texture, thiobarbituric acid reactive substance (TBARS), total aerobic mesophilic bacteria (TAMB) and total coliform (TC) counts, polycyclic aromatic hydrocarbons (PAHs) values of beef samples were examined. The lowest moisture content values (51.01 - 53.15 %) of beef samples were obtained in the hybrid cooking. pH values of cooked samples were significantly different ($P<0.05$) than raw beef. Color values (L*, a*, b*, H and S) of beef in the hybrid cooking were desirable by the consumer in terms of providing a fried shell appearance. Hybrid cooking caused a significant effect ($P<0.05$) on hardness, gumminess and resiliences of beef, however springiness, cohesiveness and chewiness values were not changed significantly ($P>0.05$). Higher voltage values and higher temperatures caused a significant increase ($P<0.05$) in TBARS values. Hybrid cooking provided the best results in terms of inhibition of TAMB and TC counts. Cooking treatments used in this study can be considered as safe about PAH content due to lower PAH levels than European Commission (EC) limits. The results of study showed that hybrid cooking is a safe and advantegous method to cook beef in terms of good quality attributes.

Key words: Ultrasound, ohmic, infrared, hybrid cooking, beef, quality and safety

ÖZET

HİBRİT (ULTRASON, OHMİK VE KIZILÖTESİ) İŞLEMLERİN ETİN KALİTE ÖZELLİKLERİ ÜZERİNE ETKİLERİ

UZUN ÖZCAN, Anıl
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Bu çalışmada, ultrason (10, 20 ve 30 dk.), ohmik (40, 55 ve 70 V) ve kızılötesi işlemlerin (325, 375 ve 425 °F) ardışık uygulaması olan hibrit pişirme sisteminin etin kalite özellikleri üzerine etkisi araştırılmıştır. Hibrit pişirme sistemi, yalnız ohmik pişirme, yalnız kızılötesi pişirme, ultrason - ohmik, ohmik - kızılötesi pişirme yöntemleri ile de karşılaştırılmıştır. Sistem değişkenlerinin, sığır eti örneklerinin nem içeriği, pH, renk, doku, tiyobarbitürik asit reaktif madde (TBARS), toplam aerobik mezofilik bakteri (TAMB) ve toplam koliform (TK) sayıları, polisiklik aromatik hidrokarbonlar (PAH) üzerine etkisi incelenmiştir. En düşük nem içeriğine (%51.01-53.15) hibrit pişirme sisteminde ulaşılmıştır. Pişirilmiş örneklerin pH değerleri çiğ olanlardan önemli ölçüde farklıdır ($P<0.05$). Hibrit pişirme sisteminde, bulunan renk değerleri (L*, a*, b*, H, S) kızarmış bir kabuk görünümü sağlama bakımından tüketici tarafından arzu edilen niteliktedir. Hibrit pişirme, sığır eti örneklerinin sertlik, sakızımsılık ve elastiklik özelliklerinde önemli derecede bir etkiye ($P<0.05$) neden olurken, esneklik, yapışkanlık ve çiğnenebilirliğinde önemli bir etkiye neden olmamıştır ($P>0.05$). Yüksek voltaj ve sıcaklık TBARS değerlerinde önemli bir artışa ($P<0.05$) neden olmuştur. Hibrit pişirme işlemi, TAMB ve TK sayılarının inhibisyonu bakımından en iyi sonucu sağlamıştır. Bu çalışmada kullanılan pişirme yöntemleri, Avrupa Komisyon sınırlarının altında bulunan PAH değerleri nedeniyle güvenli olarak kabul edilebilir. Çalışma sonuçları, hibrit pişirme yönteminin, sığır eti pişirmek için güvenli ve avantajlı bir yöntem olduğunu göstermiştir.

Anahtar kelimeler: Ultrason, ohmik, kızılötesi, hibrit pişirme, sığır eti, kalite ve güvenlik

To my dear mom, my love Nihat and my sweetheart Aras

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LIST OF SYMBOLS/ABBREVIATIONS

V	Voltage
°F	Degree of Fahrenheit
TBARS	Thiobarbituric Acid Reactive Substance
TAMB	Total Aerobic Mesophilic Bacteria
TC	Total Coliform
PAHs	Polycyclic Aromatic Hydrocarbons
EC	European Commission
UPLC- FD	Ultra-performance liquid chromatography fluorescence detector
TMEP	Tetramethoxypropane
TBA	Thiobarbituricacid
TCA	Trichloroacetic acid
MDA	Malondialdehyde
BaP	Benzo(a)pyrene

CHAPTER I

INTRODUCTION

1.1 Meat

Meat is generally defined as the animal tissue (usually cattle, swine, and sheep) used as food including not only the muscles and fat but also the tendons and ligaments. The Food Standard Code defines meat as "the full or part of the carcass of any camel, buffalo, cattle, deer, goat, pig, hare poultry, rabbit or sheep, slaughtered other than in a wild state, but does not include eggs, or foetuses" (FSANZ, 2002). Red meat is used by the meat industry refer to meat from sheep, cattle and goat (beef, lamb, veal mutton and goat meat) not from kangaroo or pigs. Beef is the name for meat from cattle (Beilken et al., 2007). Meat ranks among one of the most significant, nutritious and favored food matter accessible to people, which is significant to support body requirements. It is an essential constituent of a well-balanced diet and has played a vital role in human evolution (Ahmad et al., 2018).

Beef is a nutrient-dense food and it is an important source of a wide range of nutrients (Cosgrow et al., 2005). Beef is a well source of high quality protein that is important for having better health. As already known that protein is essential for maintenance, growth and the repair of the body and can also provide energy. Cooked beef comprises 27-35 g of protein per 100 g while raw meat has in the main, 20-24 g of protein per 100g. When it is looked from the view point of fat content of beef, lean beef consists of more unsaturated fat than saturated fat, red meat includes both saturated and unsaturated fats. Moreover, meat is an important dietary minerals source, particularly iron and zinc. Red meat contains more readily absorbed haem iron form. In England, there has been low iron intakes by approximately 50% of child-bearing age of women. A number of studies revealed that there is a positive relationship between including red meat in the diet and intaking of dietary iron. Meat also contains a many kinds of vitamins, including a chain of B vitamins, particularly vitamin B3 (niacin), vitamin B6 (pyridoxine) and vitamin B12 (cobalamin). Since vitamin B12 is found only naturally in food obtained from the animal, vitamin B12 may be inadequate in people who do not consume meat or other animal products. (Gibson and Ashwell, 2002). Meat with these all of the health aspects, it makes a valued contribution to the diet. According to recent analyses that there has been a quite tendency to prefer meat with leaner cuts over the past two decades (Williams et al., 2006).

Meat is rather variable in composition and the actual composition for a muscle will vary with the species, age, sex, and diet of the animal as well as its anatomical location (Oliphant, 1998). Nutritional composition of meat also varies in comformity with feeding regimen, breeding, season and meat cut but generally lean red meat has a low fat content, rich in protein and many essential vitamins, minerals and is moderate in cholesterol (Williams, 2007).

1.2 Meat Composition

Lean meat approximately constitues 65 - 80% water, 16 - 22% protein, 1.5 - 13% lipids, 1.5% nonprotein nitrogeneous substance, 0.3% free amino acids, 1% carbohydrates and 1% inorganic substances in wet basis (Miller, 2002).

Meat is classified as the perishable food material since its moisture content is more than 70% younger and leaner animals demonstrated about 72% moisture content. The presence of moisture in meat has a strong influence on the texture, color and flavor of meat muscle tissues, except that reduction in shelf life (Williams, 2007). By the breaking of muscle fibers, the water holding capacity of meat could be changed and thus the shelf life of the meat products could be increased. Cooking is one of the process that can affect the final water contents of meaty products (Kamruzzaman et al., 2016). The percentage of meat protein component varies according to the meat species, but generally the average value of the meat protein is about 22%. However, high protein value in chicken breast as 34.5% may be as low as 12.3% in duck meat. Protein quality is mainly depends on the amino acids availability present in it. In comparison with pork and lamb the beef has higher contents of lysine, valine and leucine. Studies have shown that the diverseness in the essential amino acid ratio in meat is due to the breed, animal age and muscle location. In other respects, if the application time of ionization radiation and heat is longer meat composition is affected from this situation much (Ahmad et al.,2018).

Carbohydrates are stored in glycogen constitute fundamentally in the liver and muscles but also they are present at lower amounts in glands and organs. The glycogen affects the meat water holding capacity, color, texture and tenderness undirectly (Jensen et al., 2011). The normal muscle pH regards about 5.6. If an animal is being exposed to extreme stress or exercise prior to slaughtering and muscles have no chance to regain their normal glycogen levels, which affects the pH level, since present glycogen is converted into lactic acid and in the end, meat muscles become dark, firm and dry (DFD). Also, drop in muscle pH leads to pale, soft and exudative meat (PSE) due to a rather speedy postmortem. DFD and PSE situations are related to the meat carbohydrate content, which affects the nutritional value of meat noticeably (Ahmad et al., 2018).

Fat content is identified as triglycerides, which is formed by the esters of three fatty acid chains and glycerol. Fatty tissue in meat is comprised of fat cells containing lipids with different fat amount. Fat content in animal carcass varies from 8 to 20%. Fat content of meat and fatty acid composition can be affected significantly by cooking. Scientific evidence revealed the considerable losses of fat in numerous meat cuts which were attributed to grilling, broiling and pan-frying without added fat (Grunert et al., 2004). Unsaturated fatty acids are present in fat tissue; oleic (C-18:1), linoleic (C-18:2), linolenic (C-18:3) and arachidonic (C-20:4) acid appear to be most common in the fatty acid composition (Woods and Fearon, 2009).

Nutrients in food materials that do not contain the element carbon in them are identified as minerals. It is apparent that, obviously potassium is quantitatively rather main mineral in meat as compared to others such as sodium, phosphorus and magnesium. Meat is also a very good source of zinc, iron and selenium. The growth, development and maintenance of the human body is provided by a wide range of all these minerals.

Table 1.1 Nutrient composition (per 100 g) of lean beef (Sinclair et al. 1999)

Constituents	100 g lean beef
Moisture	73.1 g
Protein	23.2 g
Fat	2.8 g
Energy	498 kJ
Cholesterol	50 mg
Thiamin	0.04 mg
Riboflavin	0.18 mg
Niacin	5.0 mg
Vitamin B6	0.52 mg
Vitamin B12	2.5 µg
Pantothenic acid	0.35 mg
Vitamin A	<5 µg
Beta-carotene	10 µg
Alpha-tocopherol	0.63 mg
Sodium	51 mg
Potassium	363 mg
Calcium	4.5 mg
Iron	1.8 mg
Zinc	4.6 mg
Magnesium	25 mg
Phosphorus	215 mg
Copper	0.12 mg
Selenium	17 µg

1.3 Meat Structure

Lean tissue, fat and connective tissues are the main structural components of meat. Fat or adipose cells can be found in up to three depots or locations in meat. Fat can be found as marbling between muscles or contained between muscles (defined as fat between muscles) or as external fat. Meat includes nervous tissue and blood system components but the total weight or ratio of them contributes meat slightly. Meat quality is affected by fat, lean and connective tissue in various ways (Miller, 2002).

1.3.1 Fat Component

Intramuscular fat content affects the flavor, tenderness, juiciness and visual properties of meat. In general, palatability increases as fat content increases but palatability enhancements by increasing the percentage of fat are not valid for all fatness levels. The matters about the fat content and consumption of fat in meat products has brought some questions such as coronary heart disease, some cancer kinds and obesity occurence in humans which can affect consumers perception of acceptability. Therefore, meat with intramuscular fat content between 3 and 7.3% is generally considered acceptable (Miller, 2002).

1.3.2 Lean or Muscle Fiber Component

Meat is primarily composed of lean and muscle fibers are the main component of the lean. Muscle fibers have muscle proteins that binds water or interacts with water to keep it inside. Meat juiciness and tenderness is affected by the structural unity and the muscle proteins ability to bind water (Miller, 2002).

1.3.3 Connective Tissue Component

The structural support to the muscles is provided by perimysium (connective tissue surrounding the muscle bundles) and the endomysium (connective tissue surrounding the muscle fibers). Low-use muscles, which provide structural support, have lower connective tissue content than the high-use muscles used for major movements. Higher amounts of connective tissue found in muscles are tougher (Miller, 2002).

In summary, fat, lean and connective tissue, the three major components of meat, play important role for the quality of meat with each uniquely contributing to meat tenderness, flavor and juiciness. These three components are interlinked and interact biologically within the system of muscle or meat. They are not independent components while each of these components has been discussed separately (Miller, 2002).

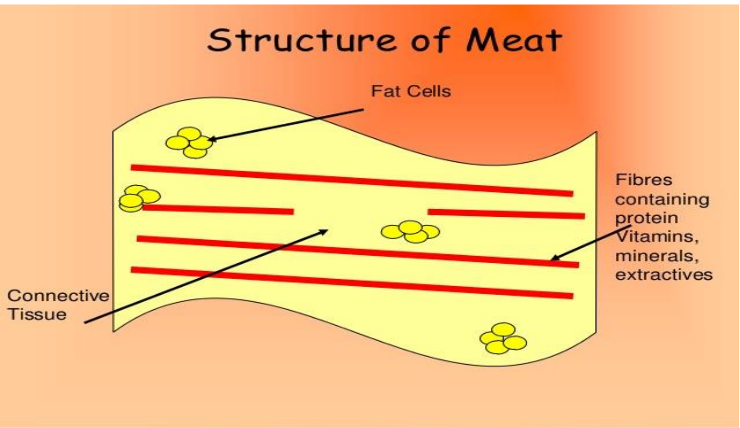

Figure 1.1 Structure of meat (Anon., 2014)

1.4 Cooking of Meat

Meat is generally cooked before consumption with the exception of specially dried and fermented products. Cooking of meat gets many advantages such as acquiring more palatable, tender meat which results better digestibility, more safer meat since harmful bacteria, parasites etc. are killed and more developed color, flavor, aroma in meat samples. Moreover, during the cooking process, physical and biochemical changes occur and sensory characteristics and microbiological quality is affected by these changes. Proteins are denatured; this has little detrimental effect on nutritional value except that over-cooking can reduce the available lysine content. From the standpoint of vitamins and minerals, meat is an important iron source and certain vitamins in the average diet. Except vitamin B1, they are relatively unaffected by cooking. The flavour of raw meat is not very strong. It is somewhat metallic, due to the iron in myoglobin and haemoglobin. Pleasant and interesting flavours are developed on cooking (Ranken, 2000).

The eating quality of meat is primely affected by the cooking method. Different methods are used for heat transfer when cooking meat in different heating methods like dry cooking (pan frying, roasting or broiling), moist cooking (boiling or braising) or microwave cooking (electromagnetic energy) (Bejerholm and Aaslyng, 2004).

1.4.1 Main Conventional Cooking Methods

Conduction, convection and radiation are the heat transfer methods in conventional cooking methods; meanwhile unconventional methods use energy provided by other means such as microwaves, infrared, ultrasound and ohmic etc. Many cooking techniques include heating the surface of the meat, heating through the outline of the meat and the heat transfer method (contact, air, water, steam or microwaves) factors. More than one type of heat transfer is often involved in meat cooking. Sometimes, a combination of dry and moist heating methods are used. Meat type, connective tissue amount and size of the meat are the deterministic factors for choosing cooking method (Bejerholm and Aaslyng, 2004). According to application type, the objective of cooking meat products will alter; however, it is always necessary to make sure that the meat is completely cooked, safe, and that all pieces of meat and areas of the meat is completely cooked, safe, and that all pieces of meat and areas of the meat piles have been heated to the required temperature to kill pathogens and coliforms (Knipe and Rust, 2010).

1.4.1.1 Boiling/Stewing/Water Bath

Boiling, stewing and water bath are cooking methods in liquid representing moist cooking methods, where the meat is cooked by being placed in a pan and covering with water. In these methods, pre-browning does not occur. The maximum temperature reached in these methods is 100 °C not higher than that temperature because, heat exchange takes place in water medium. Meats with high connective tissue content are cooked with these methods. As cooking duration is extended, meats containing high amount of connective tissue become more tender due to the dissolution of collagen. The final endpoint temperature is reached more quickly when meat is cooked in water than being cooked without water; because the specific heat of water is greater than of air. Cooking in a controlled water bath environment is generally used for research and experimental procedures. Small meat samples are placed in plastic bags and immersed in a waterbath where the temperature is set below 100 °C (Bejerholm and Aaslyng, 2004). The advantages of boiling are safe, ideal for tough cuts of meat and simple method of cooking also the meat does not get charred and digested easily. Disadvantages of boiling are slow method and water soluble nutrients, flavour, vitamins and loss of minerals into cooking liquid.

1.4.1.2 Roasting

Roasting includes simultaneous heat and mass transfer; heat is transferred into the meat from hot surfaces and air in the oven, moisture is transferred from the meat to surrounding air and then removed from the oven. In an oven, meat sample receives the heat by a combination of infrared radiation from the oven walls, by convection from flowing of air and by conduction through the pan on which the meat is placed. Infrared radiation is absorbed into the meat and converted to heat. Heat is transferred with air, moisture vapour and other gases in the oven by convection. The heat is converted to conductive heat at the meat surface. A boundary film of air acts as a resistance to heat transfer into the meat and to movement of water vapour from the meat. The velocity of the air and the surface properties of the meat mostly determines the thickness of the boundary layer and this layer controls the rates of heat and mass transfer. Many commercial designs are equipped with fans to support natural convection currents and reduce the thickness of the boundary film. Because convection currents provide homogeneous heat distribution throughout the furnace and also increases heat transfer coefficients and increases energy efficiency (Fellows, 2000). The advantages of roasting are little loss of nutrients, attractive appearance and taste. The disadvantages are slow, takes time to prepare, danger of overcooking.

1.4.1.3 Grilling and Broiling

In grilling, cooking of meat is achieved by the way of conducting heat on upper and down sides of meat. The connection between the meat and heat source affects the heat transmission. In this process, meat is placed between the plates which are heated before, fat does not added and rolling meat is not required. Meat is cooked by direct radiant heat by broiling so it is a dry heat method, temperature is high and cooking time is little. The heat source may be an oven broiler, an electric broiler or an outdoor grill and meat should be put over or under the heat source. In broiling method, the meat must be turned during cooking since the heat radiates from one direction. The method is used for cuts of meat with a low content of connective tissue such as steaks, chops and patties. The cooking time is short (Bejerholm and Aaslyng, 2004). The advantages of grilling and broiling are quick, little loss of nutrients and little preparation. The disadvantages are needs attention, not suitable tough meat and danger of over cooking.

1.4.1.4 Frying

Frying is a unit operation which is mainly used to alter the eating quality of a food. When meat is placed in hot oil, the surface temperature rises rapidly and water is vaporised as steam. Crust is formed by the level of evaporation moving inside the meat. Hot oil then causes the rising of meat surface temperature and the internal temperature rises more slowly towards 100 °C. The temperature difference between the oil and the meat and the surface heat transfer coefficient ensures the rate of heat transfer. Meat thermal conductivity controls the heat penetration rate into the meat. The crust of surface comprises of different sized capillaries, has a porous structure.

Firstly, both water and water vapour are moved out from the larger capillaries then they put in place of hot oil during frying. Heat and mass transfer rate is controlled by the thickness of boundary film of oil which the moisture moves from the meat surface with it (Fellows, 2000). The advantages of frying are quick and little preparation. Fried food has longer shelf life than meat cooked using other methods. The disadvantages are fried meat especially deep fried meat is difficult to digest and has many calories, too. Excessive consumption of fried meats can be bad for health.

1.4.1.5 Braising

When meat with a high connective tissue content it requires extreme tenderization. Braising method is the appropriate cooking method for this meat. The meat is often pre-browned and then placed in a covered pan with added often a small amount of water. The meat is cooked slowly in the moist atmosphere, and the maximum temperature reached is not higher than 100 °C (Bejerholm and Aaslyng, 2004). The main advantage of braising is very economical by means of moist atmosphere. Otherwise, meat can not be easily digestible and does not have a good taste. However, the disadvantage of braising is that it is a very slow process since cooking much hours is required prior to being served.

1.4.1.6 Microwave

Microwaves are electromagnetic waves which has the frequency ranges from 300 MHz to 300 GHz. The microwave field is an alternative magnetic field, in which, depending on the location of the electric field direction (2.45 billion times per second), polarity molecules from the original random thermal motion changes. Food substance can convert microwave energy into heat due to dielectric properties (Guo et al. 2017). Microwaves are a non-contact heat source that have been used in the food industry for drying, tempering, bleaching, sterilization and extraction. The advantages of using microwave energy, relative to conventional processing, is that it provides more effective heating, faster start up, faster energy transfer, reduced thermal gradients, better heating control and eliminates processing steps, which results in increased production (Proctor, 2011a).

One of the cooking problem in microwave is due to the low meat surface temperature and the low temperature of the surrounding air, maillard reactions do not occur in microwave cooking and therefore the meat surface does not brown. If the microwaveoven is supplemented with another heat source, such as convection, browning of the surface occurs. Another problem is uneven heating of meat samples. Microwave cooking is not recommended for meat with a high connective tissue content, since it is not accomplishable to convert the collagen in the meat to gelatin during short-term cooking (Bejerholm and Aaslyng, 2004).

1.4.2 Alternative Novel Treatments and Cooking Methods

The last century has witnessed a dramatic increase in the development of new technologies, which in many cases replace the conventional methods (Cummins and Lyng, 2017a). The uniformity of heating of particulate foods for existing processing technologies remains a problem. Conventional heat treatment generally heats the food to compensate for the thermal lag of the particles and therefore significantly reduces the organoleptic and nutritional quality of the products (Choi et al., 2011). Conventional cooking methods can cause some parts of the food product to overcooked or undercooked, which may adversely influence the quality. Because it takes a considerable amount of time to deliver sufficient heat to the food product core to reach a safe end-point temperature. In recent years, it has been seen that consumer demand has increased towards the high quality products which are produced by using alternative technologies and especially electrical processes have gained importance as alternative minimal processing technology and as potential methods (Bozkurt and İçier, 2010). Developing alternative technologies and products are also essential to move the food industry, and other industries, towards sustainable processing and to reduce commercial energy use and thereby responsibly preserve local and global environments (Proctor, 2011c).

A global product, meat, is traded between regions, countries and continents. It is very important to develop new innovative methods for processing, packaging and evaluating such dynamic and marketable meat products. Several new technologies have emerged with regard to meat processing which have the potential to improve production efficiency while maintaining meat safety and quality. A number of novel thermal and non-thermal technologies designed to achieve microbial safety have minimally influenced the nutrients and quality of food. Applications of new and innovative technologies and resulting effects to meat products either individually or in combination are great interest for meat processing (Cummins and Lyng, 2017a). Ultrasound treatments, ohmic cooking and infrared (IR) radiation heating has been considered as an alternative novel technology to current meat processing methods for improving product quality and safety, increasing energy and processing efficiency, and reducing chemical usage.

1.4.2.1 Ultrasound Treatment

Ultrasound can be defined as a mechanical vibration above the audible sound spectrum (18 kHz and higher). In another words ultrasound starts when the human hearing ends. Ultrasonic waves are affected by some factors that affect sound as the density of the material/medium and they also share the same properties (wavelength, amplitude, etc.). Power ultrasound (low frequency, high power ultrasound; 18 kHz to 100 kHz), extended power ultrasound (high frequency, medium power ultrasound; 100 kHz up to 1 MHz) medical and diagnostic ultrasound (high frequency, medium power ultrasound; 2 MHz to 10 MHz) are the three major areas of ultrasound. Hypersonic sound is named when the ultrasound continues up to 1 GHz (Gonzales, 2003).

Ultrasound is one of the novel innovative technologies which is developed to obtain maximum quality with minimum processing time meanwhile ensuring the food safety. Ultrasound treatment has many beneficial effects on food processing such as food preservation, improved mass transfer and texture, supporting thermal treatments and applications of food analysis (Knorr et al., 2011). Ultrasound techniques are simple, cost and energy efficient, and therefore became an emerging technology which is used to examine and modify food products. Physicochemical properties and the composition of food components and products during processing and storage are determined by low power (high frequency) ultrasound, which is crucial for controlling the food properties and to improve the food quality. On the other hand, mechanical, physical and chemical/biochemical changes are stimulated by High power (low frequency) ultrasound through cavitation, which is used as a support in many food processing operations such as freezing, drying, emulsification, extraction, and inactivation of pathogenic bacteria on food contact surfaces (Awad et al., 2012). Recent years, there is a great interest in ultrasound because practical and reliable ultrasound devices can support the industries. Nowadays, it has pointed out the issue of environmental sustainability with the emergence of green novel technology. Ultrasound applications are based on three different methods: 1- Direct application to the product, 2- Coupling with the device and 3- Submergence in an ultrasonic bath (Chemat et al., 2011).

Figure 1.2 Ultrasonic bath (Chemat et al., 2011)

Tenderization of meat, curing and pickling of meat, sausage production, meat industry effluent treatment, meat cooking and cleaning the equipments in meat industry are the applications of ultrasound in meat processing (Cummins and Lyng, 2017b). Among these applications, ultrasound is very succesfull for tenderizing so obtaining improved cohesiveness and water-binding property of meats (Lawrie, 2006). During the meat curing and pickling process, by the help of ultrasound, meat sample is meeting with the pickling solution in a very short time (Misra et al., 2017). Carcel et al. (2007) have reported that above a critical ultrasonic intensity (51W/cm), the applied ultrasonic intensity is proportioned to the uptake of brine into meat. In their study, at the highest level of ultrasound application, the total brine uptake was significantly higher than the initial water content of the meat. For the production of sausages, the toughening of the meat emulsions used for sausage filling results from the ultrasound application to the cylindrical sausage extruder unit (Manna et al., 2000). For meat industry effluent treatment ultrasonic pre-treatment enhances the biodegradability of wastewaters, including those containing resistant organic substances (Mahamuni and Adewuyi, 2010). Ultrasound cooking caused some structural changes such as sarcomer length, fibre size and destruction of myofibrillar at higher level (Pohlman et al., 1997b). The work of Pohlman et al. (1997b) revealed that ultrasound cooking (20 kHz, 1000W) provides many benefits like cooking speed increasing (6.7 min), better retentivity of moisture, better cooking yield (2 – 5 times) and better energy efficiency (0.08W/g) for beef Longissimus. Despite the several benefits identified in the literature, it is to be noted that the most important disadvantage of ultrasound cooking is that it contains poorer flavour (Pohlman et al., 1997a) compared to conventional cooking methods (e.g. roasting and grilling). For cleaning, studies point to the fact that integrating an ultrasound with an antimicrobial agent into existing cleaning procedures in the meat and poultry industry can be used to improve the efficiency of the cleaning process (Allen et al., 2008a , Allen et al., 2008b, Leps et al., 2013).

1.4.2.2 Ohmic Processing

During the flow of electrical current through a conductor the motion of charges within the material results in excitation of molecules (or atoms) on its way, which results an increase in the temperature. The moving charges in metallic conductors are electrons; however ions or other charged molecules such as proteins, which migrate to the electrode of opposite polarity are the moving charges within food materials. (Ramaswamy et al., 2014).

Ohmic process is based on the flow of electrical current through a food material with an electrical resistance. The amount of heat that is instantly generated inside the food is directly proportional to the the electrical conductivity and voltage gradient (Yıldız-Turp et al., 2013).

The success of ohmic heating depends on the heat generation rate, the electrical conductivity of the food, strength of electrical field, residence time and the food flowing method through the system. The food acts as a resistor. The dissipation of electrical energy causes heating of the substance. Heating with electrical resistance allows particles and liquids to heat at the same rate and allows rapid heating of mixtures with high solid content (Varghese et al., 2014).

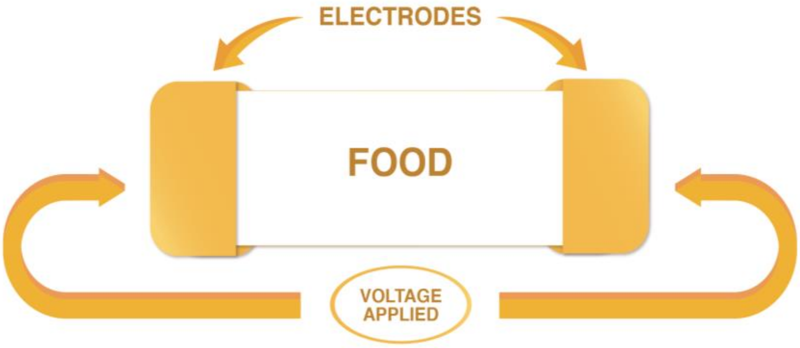

Figure 1.3 Ohmic heating system (Sun, 2006)

Ohmic heating is also known as Joule heating and resistive heating and it was first studied by James Prescott Joule in 1841. Joule immersed a length of wire in a fixed mass of water and measured the temperature rise due to a known current flowing through the wire for a 30-min period. By varying the current and the length of the wire, he deduced that the production of heat is proportional to the electrical resistance of the wire multiplied by the square of the current. This relationship is Joule's First Law where Q is rate of evolution of heat in watts, the unit of heat being the joule; R is resistance in ohms; and I is current in amperes.

$$Q = I^2 \times R \qquad (1.1)$$

George Simon Ohm (1789–1854) determined that the potential difference (voltage, V in volts) applied across a conductor changes directly proportional with the resultant electric current (I in amperes). Ohm's law is given by the equation

$$V = I \times R \qquad (1.2)$$

where R is the electrical resistance measured in ohm. Since, the heat results from the electrical resistance, it is referred to as "ohmic" heating. Other synonyms are used in the literature to describe this principle of heating: direct resistance heating, electroconductive heating, and electroresistive heating (Ahmed et al., 2010).

The ohmic system make allowance for the production of high-added-value, new and high quality products, especially for particulate foods and does not allow a large temperature gradient within the food. In ohmic heating, the sudden heat formation in food is caused by the current flowing through the food. Homogeneous temperature distribution is realized and volumetric heating occurs. Moreover, a temperature difference of 55ºC can be achieved in less than one second (Reznick, 1996). It has so many advantages but its major advantages are: by contrast with microwave heating, which has a very high penetration depth into solid materials, the ohmic process provides continual production without the heat transfer surfaces, rapid processing of liquid, minimal heat damages and nutrient losses of solid phases. Ohmic process is also ideal process for shear-sensitive products since low flow velocity, capital investment optimization and product safety as a result of high solids loading, reduced fouling when compared to conventional heating. It is also simpler and has better process control with reduced maintenance costs, environmentally friendly system (Sun, 2006). Ohmic heating is much more efficient than microwave heating. Because there is not any penetration depth limitation in ohmic heating and almost all of the energy enters food. No physical contact is required for microwave heating however, ohmic heating process requires the use of electrodes in good contact with the food (Li and Sun, 2002).

Ohmic processing used for many applications such as blanching, on-line detection of starch gelatinization, thawing, peeling, fermentation, dehydration, evaporation and extraction. Lima and Sastry (1999) investigated ohmic pre-treatment of fruits and vegetables and examined the ohmic heating frequency effects on hot-air drying rate and juice yield. Sensoy and Sastry (2003) studied for blanching mushrooms by ohmic heating. Zareifard et al. (2003) determined the ohmic heating behavior and electrical conductivity of two-phase food systems. Piette et al. (2004) studied the ohmic cooking effect on the quality of processed meats. Sastry et al. (1999) indicated that ohmic cooking can be applied alternatively to meat products treated in the traditional smokehouse.

1.4.2.3 Ohmic Processing in Meat

Meat is a complex food material consisting of muscle fibres and connective tissue with a certain amount of intramuscular fat, and its ohmic heating behaviour will only approach any degree of uniformity in a finely comminuted structure. Electrical conductivity of processed foods has a critical impact on ohmic heating rates (Zoltai and Swearingen, 1996). The lean component of meat generally has a higher electrical conductivity than fat since fats and oils are electrically too resistive (Proctor, 2011b).

There has been many succesfull applications of ohmic processing in meat. One ohmic application is the thawing process in meat while traditional thawing methods are not very succesfull for providing superior products. According to Wang et al. (2002) study results, frozen meat samples applied by the technology of liquid contact thawing method showed a uniform and faster thawing process, also it was not a significant change on pH and color values and the final products demonstrate a better thawing quality. These results present the possible uses of ohmic process in contact thawing, notably for meat products. Another ohmic application is the cooking of meat. Canadian scientists (Piette and Brodeur, 2001) have been working on the ohmic cooking of meat products (sausages and ham) with encouraging potential results in batch operations. When brine-cured meat products were exposed to ohmic process, time of cooking is exceedingly lowered. Moreover, the products characteristic such as texture, taste or shelf life were not changed noticeably. Bozkurt and İçier (2010) made a comparison between ohmic cooking (20, 30 and 40 V/cm) and conventional cooking of beef samples with different fat contents (2%, 9% and 15%). In their study, similar results were obtained in terms of cooking yield in ohmic cooking and conventional cooking process. While a more homogenous color was observed in ohmic cooked ground meat samples, the crust layer could not be obtained on the ground meat surface. They indicated that ohmic cooked samples were firmer than conventionally cooked samples whereas voltage gradient and fat content did not have a significant effect on the firmness and toughness of samples. They also indicated that ohmic cooking was faster than the conventional cooking.

1.4.2.4 Infrared Cooking

Infrared energy is emitted in the form of electromagnetic radiation by hot objects. It gives up its energy which heats materials when it is absorbed. The heat transfer rate depends on the shapes and the surface temperatures and properties of the materials where the heat transfer occurs between (Fellows, 2000). When IR radiation contacts a food surface, the IR energy is absorbed at certain frequencies in correspondance with intra-molecular transitions between energy levels according to the nature of the chemical bonds present. The wavelengths of IR fall in the spectrum of 0.76±1000 µm and can be typically classified into near infrared (NIR) (0.76±2 µm), medium infrared (MIR) (2± 4 µm) and far infrared (FIR) (4±1000 µm) (Pan and Atungulu, 2010). In general, in food processing, since the food is damaged by the high load energy in NIR and absorbtion of energy is higher in the FIR wavelength range, the FIR heater is used more than the NIR heater. Far-infrared radiation (FIR) heating has gained importance depending upon the development of commercial FIR heaters, that have high emissivity in the long wavelength infrared region.

The features of IR heating for food processing are as follows:

• Processing time and energy costs are decreased by the efficient heat transfer to the food.

• Ambient temperature can be kept at normal levels because the air in the device is not heated.

• High safety and controllability can be provided by designing compact and automatic constructions.

• Since the danger of overheating depending on the rapid heating rates, accurate heating control is needed (Sun, 2006).

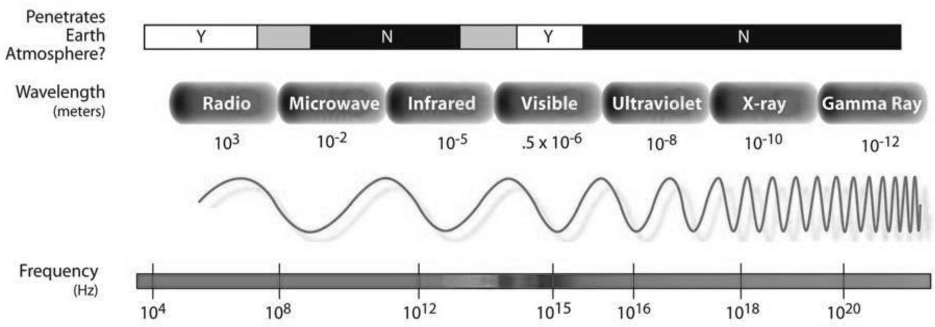

Figure 1.4 The electromagnetic spectrum (Sun, 2006)

In a cooking process, as well as dark surface (burning) colors and moisture profile in the food, the physical change like crust formation, protein metamorphism, and fat melting should be controlled appropriately. FIR provides the rapid surface heating of foods and it can be used to seal in fat, moisture and aroma compounds without burning the surface and results highly satisfactory sensory properties of products (Sun, 2006).

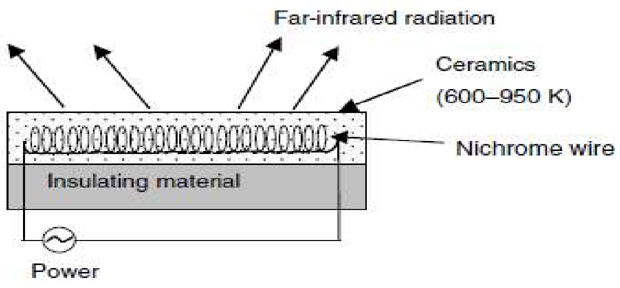

Figure 1.5 Far-infrared heater (Sun,2006)

Due to the fact that conventional baking ovens using high speed hot air convection lead to surface degradation, overheating, oxidation, shrinkage, impact damage, low efficiency, difficult emissions and high energy costs, infrared cooking has gained particular importance for the food components and processed meats sector. Infrared radiation has internal temperatures to achieve these targets, because there is no direct intention or requirement for heating air, lowering oven temperatures and humidity. Energy saving and preservation of cooked out material thus are provided that will not be lost to vaporization by high oven temperatures. Therefore, more compact equipment can be used with more exact temperature control (Sheridan and Shilton, 1999).

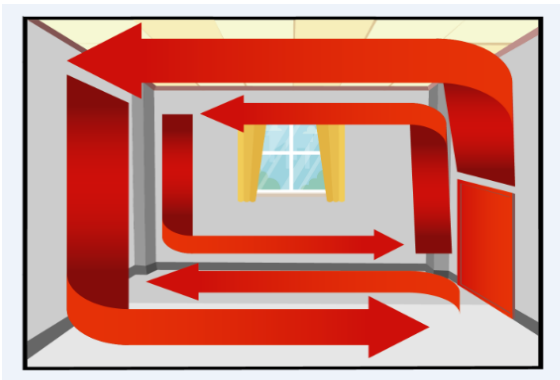

Figure 1.6 Heating path of conventional infraredheating system

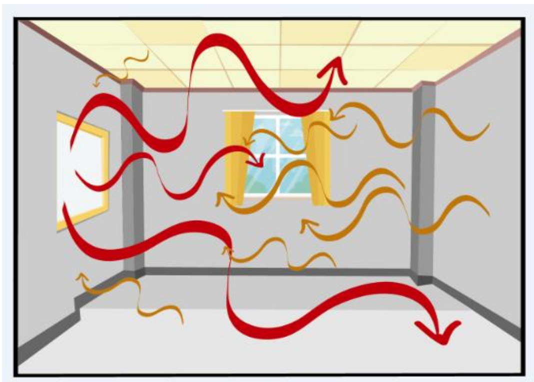

Figure 1.7 Heat distribution from heater panel

1.4.2.5 Hybrid Cooking

A hybrid is also anything that is a mixture and combination of two or more things thereby it has qualities relating to them. In this study, more than one treatments which were ultrasound, ohmic and infrared used for meat cooking so hybrid cooking should be named for this consecutive application. The main purpose of using ultrasound before ohmic cooking is to assist ohmic heating from the point of reaching a more uniform temperature dispersion on the beef muscle. Moreover, using infrared cooking after ohmic cooking provides crust layer formation on the surface of meat which is the lack of ohmic system. There isn't any study about the combination of ultrasound, ohmic and infrared but there are some studies about the combination of some cooking systems on meat and also other foods. Özkan et al. (2004) combined ohmic and conventional cooking of hamburger patties and were succeesfull for reducing cooking time and producing safer products. Jun et al. (2011) studied the microwave and ohmic combination heating and they indicated that evolving and progressing of a microwave and ohmic combination heater with a continuous flow can minimize overprocessed or underprocessed heat treatment. Yıldız-Turp et al. (2016) studied the quality characteristics of ohmically pre-cooked beef meatballs via infrared cooking as a final stage. The appearance of ohmically pre-cooked meatball samples was improved via infrared heating and the texture of the samples was also improved with these parameters. Another challenge study carried by the Isleroglu et al. (2015) is the effect of steam-assisted hybrid cooking on textural quality characteristics, cooking loss, and free moisture content of beef. The steam-assisted baking oven used in the study is a hybrid oven having an inner steam generator mounted at the back panel of the oven. They used steam-assisted baking oven which is hybrid oven having an inner steam generator mounted at the back panel of the oven and found that steam introduced in the oven chamber causes fast cooking of beef, tough texture, high cooking loss, and low free moisture content.

1.5 Changes of Quality and Safety Parameters of Cooked Meat

When cooking, meat core temperature increases the range between 0 °C and 85 °C, while the surface temperature of the meat can increase to very high temperature up to 300 °C dependent upon the cooking method. Both the meat structure and the distribution of water in meat are changed grandly by the increase in temperature. Once, the proteins denature and collagen shrinks, fat melts and drips out, water is squeezed from the muscle fiber out of the tissue (Bejerholm and Aaslyng 2004). Depending on these fundamental changes, many quality and safety parameters of meat such as moisture content, pH, colour, texture, lipid oxidation, microbial load level will alter and polycyclic aromatic hydrocarbons could be formed.

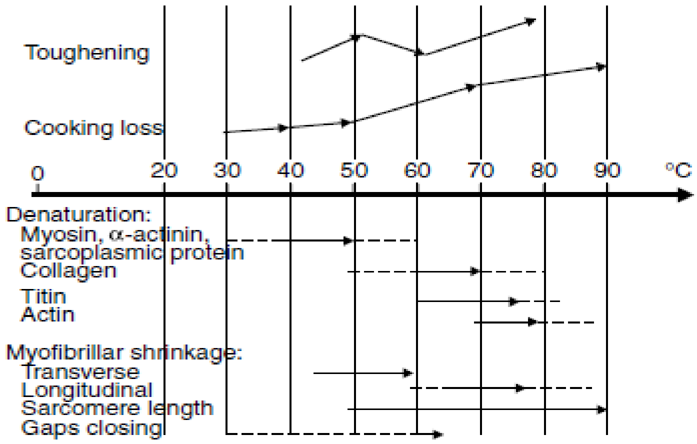

Figure 1.8 Changes in meat during cooking (Bejerholm and Aaslyng 2004).

1.5.1 Moisture Content

The water is released and vaporized by thermal processing. The water-reducing drying is due to a reduction in humidity levels on the product surface. A lower water activity environment is required to reduce the growth of survival and re-contaminating bacteria. Product temperature, cooking time, humidity and environmental conditions of temperature mainly affect the degree of water loss. There is a large increase in water loss in the temperature range between 50 and 60 °C. When the temperature reaches to 80 °C, water loss is being up to 80 to 100% of total loss by the time (Sun, 2006). Since it has a significant affect on taste, moisture content in cooked meats is important. Cooking degree of food could be comprehensible by means of its moisture content since patties cooked as insufficient will be moist but patties cooked as much will be hard (Özkan et al., 2004). During cooking, due to the protein denaturation, myofibrillar structure rigidness is increasing and thus water loss is increasing with cooking (Yıldız-Turp et al., 2016).

In the beef industry, ultrasound tretament has been a fast, reproducible and reliable technology to enhance genetic improvement programs for livestock and to provide quality control of meats (Awad et al., 2012). Pohlman et al. (1997a) reported that in their study, ultrasound cooking was faster, had greater moisture retention and less cooking loss, and used less energy.

Ohmic treatment resulted in faster cooking of meat therefore it shows significant acceleration of the water removal. Özkan et al. (2004) studied combined ohmic and conventional cooking of hamburger patties. Quality measurements of the meat patties cooked by the ohmic and the conventional method showed similar moisture content.

In the infrared cooking process, the surface holds more air-filled holes as the water content in the surface is diminished due to forming an efficient insulation. As the meat crouches after dehydration during cooking, nearly 10% air gap is left inside which provides the insulation layer (Shilton et al., 1999).

1.5.2 pH

Acidity of meat is measured with pH. The pH in a normal living muscle should be around 7.2. When muscle turns into meat after slaughtering, pH levels may decrease from 5.4 to 5.7 in ordinary meat because glycogen is broken down into lactic acid during this process. If the pH drop is fast (if it is still hot, may affect the muscle proteins) or is spaicous (giving a low final pH), the meat is Pale, Soft and Exudate (PSE). Therefore, the pH of raw meat has an intense impact on color, hardness and water-holding capacity, as well as slim effects on flavor, tenderness and post-mortem conditioning rate. (Swatland, 2002).

Got et al. (1999) reported that ultrasound treatment caused to increase in pH value of meat in their study. They declared that the release of ions from the cell structure into the cytoplasm or a change in the protein structure may cause an increase in pH. This leads to a change in the position of some ionic groups and facilitating them to promote in muscle buffering. Torley et al. (2007) also observed that the pH of the *Longissimus lumborum et thoracis* increased progressively with increasing ultrasound treatment time.

1.5.3 Color

Cooking causes to myoglobin denaturation by heat inducing and exposion of heme to the external environment. Cooked meat that has a dullbrown internal color is caused by the generation of brown ferrihemochrome (as known as denatured globin hemichrome) which is the denaturation of globin in metmyoglobin (metMb).

Thermal stability of myoglobin and internal cooked meat color formation is influenced by many factors. Temperature causes to increase the heat-induced denaturation rate and extent in livestock and poultry myoglobins and according to numerous studies report minor redness in meats cooked to considerable relative inner temperatures than the ones at reduced temperatures. The color of meat is crucial quality parameter for the costumer's approach and influences their choice. Meat is a perfect source of nutrition, but it is not bought or consumed if its aspect is not in line with costumer's expectation standards. The role of myoglobin in meat color has been extensively researched and its biochemistry/chemistry continues throughout the preservation and display of the postmortem muscle of meat producing farm animals (Toldra, 2017).

Ultrasonic treatment can provides a superior color by replacing or reducing salt in beef roll production (Vimini et al., 1983). Bozkurt and İçier (2010) made a comparison between ohmic and conventional cooking of ground beef samples and higher L* (lighter) and lower a* (less red) values were found at ohmic cooked samples. While a more homogenous color was observed in ohmic cooked ground meat samples, the crust layer could not be obtained on the surface. Similarly, Zell et al. (2009) reported that ohmic cooked sample showed a whiter colour than conventionally cooked samples which had darker surfaces.

Infrared radiation results a high surface temperature formation within a minute during the heating of meat. The surface of the meat sets free cellular water and evaporation is starting on the meat surface. The formation of crust is realized by removing of all surface water while heating is in progress. This results the formation of a classic surface zone and evaporation boundary which are in below the surface. A darker color (lower L* value) of both inside and outside meat surface is evolved by infrared cooking process (Yıldız-Turp et al., 2016).

1.5.4 Texture

The feeling in the mouth sensed during chewing is determined by the texture of meat. Meat structure is impaired when it is brought in the mouth. Chewing causes the breaking down of meat structure and soaking it in saliva to make ready for swallowing. Both enzymatic breakdown of the proteins and heat-induced structural changes are the changes in meat texture during cooking (Bejerholm and Aaslyng, 2004).

As a result of the ultrasound disrupting the myofibrils of the meat which releasing a sticky exudate, the meat is binding to each other and the strength of the reformed product increases (Mason et al., 1996). Tenderness is the most important palatability factor to determine the meat quality according to consumer manners. A study (Roberts, 1991) about the sonicating of sirloin steak beef samples at 2 W/cm^2 for 2 h at 40 kHz showed that improved eating texture is resulted by the injury of perimysal connective tissue. Water-binding capacity, cohesiveness and tenderness are the physical properties achieved by ultrasound (Chemat et al., 2011).

Bozkurt and İçier (2010) investigated textural properties of ohmic and conventional cooking of meat in their study. They reported that in ohmically cooked samples, shrinking and toughening of collagen without any loosening would have resulted by exposuring high temperatures in a short-uniform. However, in conventional cooking of ground beef samples, exposuring high temperatures over longer periods of time and collagen loosening would have been more common.

1.5.5 Lipid Oxidation

Lipid oxidation is a major cause in flavour deterioration of muscle foods. In general, quality degradation of foods, especially in muscle foods, results from changes in lipid components by both enzymatic and non-enzymatic lipid oxidation processes. Lipid oxidation causes loss of essential fatty acids, as well as undesirable changes in color, flavor, texture and functional properties. It also causes the formation of cholesterol oxides and destruction of fat-soluble vitamins (Shahidi, 1998).

Lipid oxidation that occurs during cooking of meat is the most important source for the formation of taste and odor compound. However, rancidity, undesirable odours texture modification and nutritional losses is the main cause of this product degradation. Enhancement of oxidation reactions in meat depends on the temperature, time and method of cooking (Broncano et al., 2009).

1.5.6 Microbial Load

Cooking to temperatures at which the meat "looks cooked" is usually sufficient, or better, use thermometers to measure core temperatures, which should be 70 °C, 158 °F, or higher. In most cooking processes spores are not killed but they will present no problem so long as they are prevented from growing by carrying out the following processes properly which are cooling thoroughly, in clean condition and avoiding cross-contamination (Ranken, 2000).

Thermal processing is applied to meat for two main purposes which are lowering the content of microorganisms that influence the shelf life and enhancing safety of the end products by killing the food-borne pathogens. In course of slaughter, fabrication and after handling, spoilage or pathogenic microorganisms contamination arises, while interior animal tissue is considered to be sterile. Time and temperature are the important parameters which demonstrate the microbial destruction effectivity. Design of thermal processes to eliminate food-borne pathogens and to reduce the types of degradation is very valuable. Because microorganisms are always grow on fresh meat and the ingredients used in the preparation and, they are able to grow on meat products. (Sun, 2006).

1.5.7 Polycylic Aromatic Hydrocarbons (PAHs)

The polycyclic aromatic hydrocarbons (PAHs) are composed of two or more combined aromatic rings, a great group of lipophilic organic chemical polluters and stable. PAHs can be generated throughout the organic material pyrolysis and partial combustion and are usual by-products of many industrial processes such as food processing and preparation. Light PAHs contain up to four fused benzene rings, while heavy PAHs contain more than four benzene rings. Heavy PAHs are more toxic and more stable in comparison with light ones (Wenzl et al., 2006). PAHs are potentially carcinogenic and their presence in food, even at low levels, is undesirable (Lawley et al., 2008). There are approximately 660 different compounds belonging to the PAH group. Many institution such as International Agency for Research on Cancer (IARC), Agency of Toxic substance and Disease register (ATS-DR), Environmental Protection Agency and European Union has mentioned PAHs in primacy pollutant list owing to their carcinogenic and mutagenic properties. The

International Agency for Research on Cancer (IARC), the Environmental Protection Agency, the Agency for Antimicrobial and Disease Agency (ATS-DR), and the European Union have categorized PAHs in the list of priority contaminants because PAHs have mutagenic and carcinogenic properties. These PAHs are acenaphthylene, benz(a)anthracene, anthracene, dibenz(a,h)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, benzo(k)fluoranthene, benzo(b)fluoranthene, chrysene, naphthalene, fluoranthene, indeno(1,2,3-cd)pyrene (IP), phenanthrene, pyrene (Singh et al., 2016). PAHs may be considered as potentially carcinogenic and genotoxic to humans. Their carcinogenicity is induced by diolepoxides which are the metabolic transformation in mammalian cells as a result covalently bound to cellular macromolecules, including DNA, causing errors in DNA replication and mutation (Phillips and Grover, 1994). The structures of some polycyclic aromatic hydrocarbons are shown in Figure 1.8 at below.

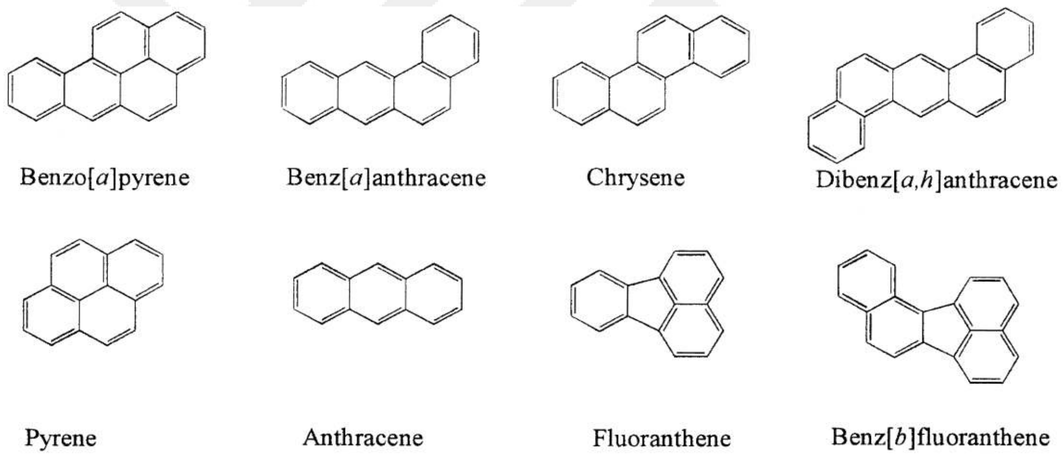

Figure 1.9 Structures of some polycyclic aromatic hydrocarbons (Phillips, 1999)

Benzo [a] pyrene (BaP) is the best known carcinogenic PAH that indicating the presence of total PAH in smoked foods especially. In 2008, European Food Safety Authority (EFSA) published an opinion on PAHs (EFSA, 2008) and deduced that BaP alone was not a suitable general determiner for PAHs in food, but identified a group of 4 PAHs (PAH4) as better indicator based on data relating to occurrence and toxicity (Rose et al., 2015). PAH4 is the sum content of four PAH compounds as; benzo(a)pyrene, benz(a)anthracene, chrysene and benz(b)fluoranthene. The formation of PAHs results in the cooking of food, particularly meat, in open flame. When there is a direct contact between the meat and the flame, PAHs are produced in the meat because of fat pyrolysis and so PAHs can accumulated in the meat. If there is not a direct contact between the meat and the flame, fat is dripping on to the flame and the generated compounds are brought back in to the meat by hot coal (Phillips, 1999). Cooking of meat at high temperatures also produces polycyclic aromatic hydrocarbons (PAHs). Polycyclic aromatic hydrocarbons (PAHs) are generated during barbecuing or grilling of meat and in smoked meats or cured meats (Sinha et al., 2005).

According to European Commission (EC) regulation, maximum acceptable levels of BaP and PAH4 in smoked meat and smoked meat products was reported as 5 µg/kg and 30 µg/kg, respectively until 31.08.2014 but as from 01.09.2014 maximum acceptable level is 2 µg/kg for BaP and 12 µg/kg for PAH4 (EC, 2011). Since there is not any limit indicated by EC for other meat products, judgements were made according to EC limit for smoked meat.

PAH formation can be resulted cooking of meat and meat products by ohmically. Also, in infrared cooking, since the higher surface temperatures (more than 120 °C) of the meat can be reached, PAH formation should be evaluated. The effect of ohmic preheating and infrared cooking combination on meatballs PAHs levels with different parameters as distance of application, cooking durations and heat flux was studied by Kendirci et al. (2014). Semi-cooked meatballs (75 °C, 0 s holding time, 15.26 V/cm voltage gradient) had 4.44 ± 1.90 µg/kg total PAHs, however, infrared cooking after ohmic cooking pre-treatment, total PAHs level was reported as 4.47–64 µg/kg.

1.6 Aim of the research

Meat is the main constituent of our diet and it is a nutritious, protein-rich food which is highly perishable and very much susceptible to spoilage. Usually, meat has to be cooked before being consumed. Cooking of meat is essential to achieve a palatable and safe product. Cooking causes several positive effects on meat such as improved digestibility, taste and flavour enhancement, shelf life increase and microorganism destruction but also produces some negative effects like polycyclic aromatic hydrocarbons (PAHs) generation and vitamin and mineral losses and changes in the fatty acid composition due to lipid oxidation.

A great number of techniques have been used to cook meat, however the variety in cooking duration, energy consumption and meat palatability prevent the universal use of any single technique. Fast heating rates can be achieved with microwave cooking but it results in inferior cooking yields, less tender and less flavorsome meat. In a conventional cooking method, when foods are subjected to high temperatures, the outer layer may be overcooked meanwhile middle parts are insufficiently cooked, therefore reducing the product quality. Steam cooking or immersion in hot water leads to low rate of heat penetration to the center of meat. That means long cooking times, where outer layers of the meat receive a more severe heat exposure than the centre which potentially reduces the quality of the outer layers of such products. Roasting, grilling and broiling methods have danger for overcooking. Radio frequency cooking and other electromagnetic waves cooking methods are in a complex structure and hard to apply. However, an economic and simple alternative cooking method suitable for both catering sector and industrial use is required. Ohmic cooking is one of the most advantegous among the alternative methods but to increase the effectiveness of ohmic cooking it should be combined other methods to form hybrid process.

The aim of the study was to

- develop an alternative cooking method of meat by using ultrasound, ohmic and infrared treatments and their combinations,
- determine the most proper cooking method of meat which is reliable and safe parameters provided,
- determine the optimum conditions (thickness, voltage and time) for the minimum processing by a hybrid cooking technology of meat,
- investigate the effect of hybrid cooking of meat on moisture content, pH, color, texture, lipid oxidation, polycyclic aromatic hydrocarbon (PAH), total aerobic mesophilic bacteria (TAMB) and total coliform (TC) count values.

By these scientific informations, lighten to the literature and contribute to the economy.

CHAPTER II

MATERIALS AND METHOD

2.1 Materials

Beef - *Longissumus dorsi* muscle was obtained from a local supermarket in Gaziantep, Turkey. The meat was frozen at -70 °C until used for cooking. The required meat samples was removed from the freezer and allowed to thaw at 4 °C for one day. Standard PAH that is EPA Method 8310 PAH mixture and Pinnacle II PAH 4 µm column (LC columns, 50 × 3.2 mm, USA) was purchased from RESTEK. All chemicals required for calibrations and analyses were UPLC grade. Thiobarbituric acid (TBA), tetramethoxypropane, trichloroaceticacid (TCA) and the rest of all reagents and solvents used in this study were purchased from Sigma-Aldrich.

2.2 Flow Diagram

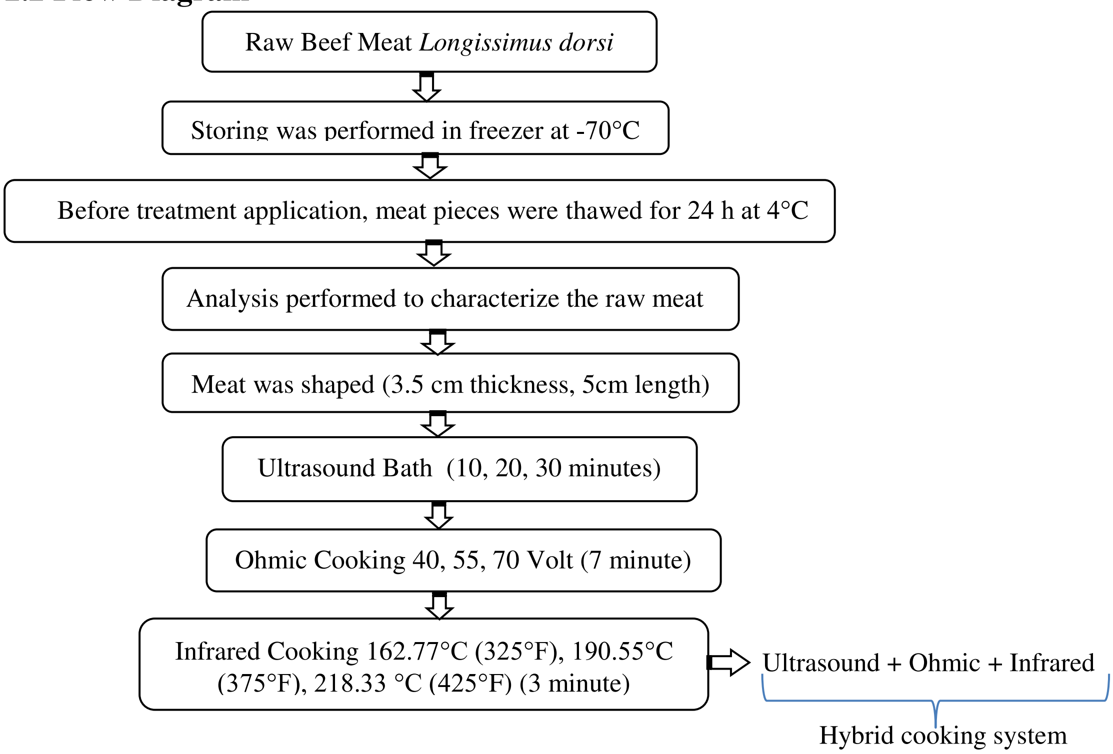

Figure 2.1 Flow Diagram of Hybrid Cooking System

2.3 Experimental Set-Up

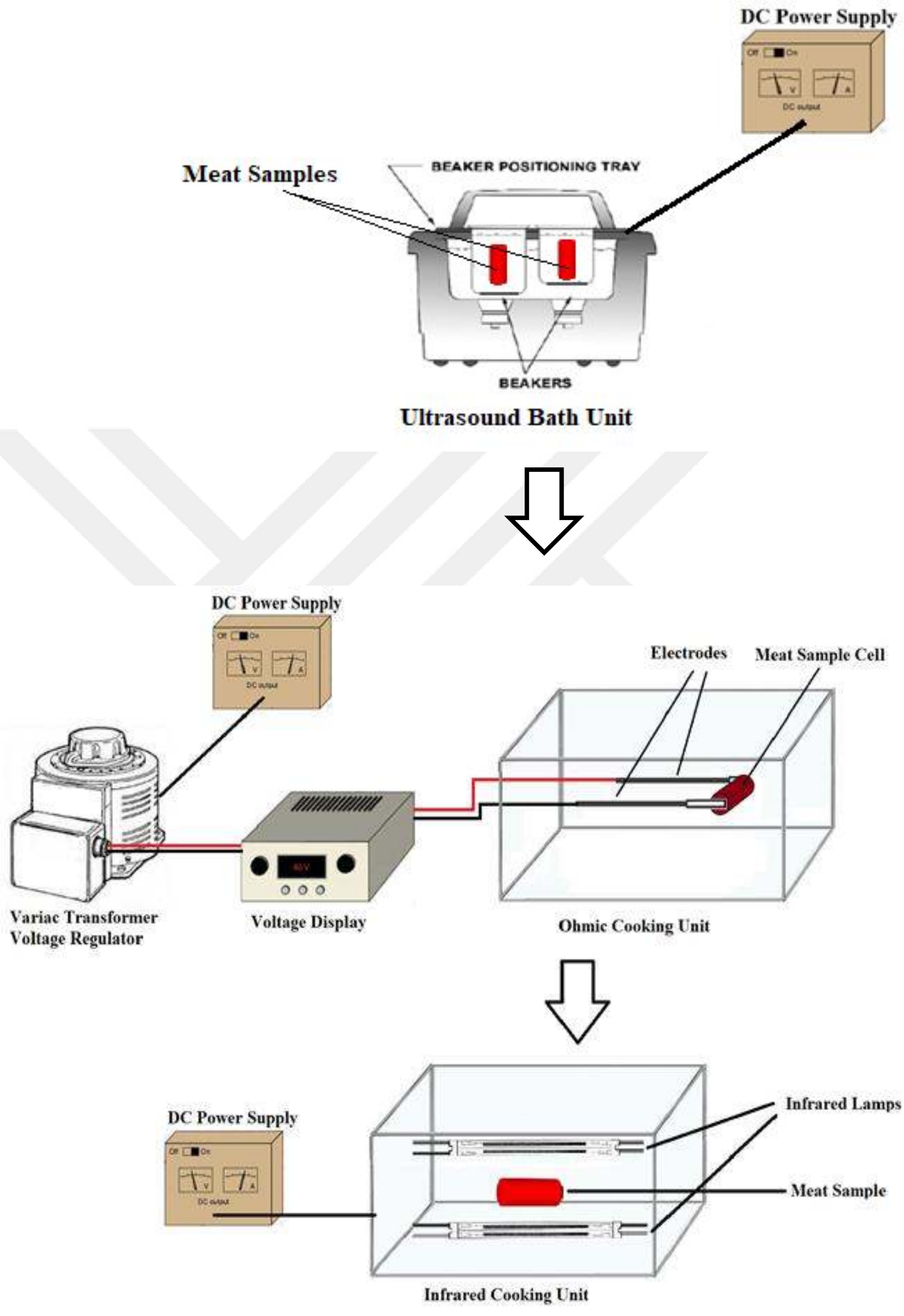

Figure 2.2 Experimental Set-Up of Hybrid Cooking System

2.4 Ultrasound Treatment

Ultrasound treatment was performed at three different times which were 10, 20 and 30 minutes in ultrasound bath (Branson B-2200 E4, 47 kHz, 60 W, USA) at room temperature. The ultrasound treated meat was used for ultrasound-ohmic and ultrasound-ohmic–infrared cooking.

Figure 2.3 Ultrasound Bath

2.5 Ohmic Cooking Procedure and Electrode Designation

For the designation of ohmic cooker, a 5 kW conductor, a 220- 24 Volt power supply, a limit switch, a 10 A fuse, a voltmeter and an ampermeter was used. Ohmic cooking design is given in Figure 2.4. For the conduction of electric current into meat sample forks were used as electrodes firstly (Figure 2.5). As shown in the Figure 2.6, uniform cooking couldn't be achieved in ohmic cooking by using forks as electrodes. For this reason, electrode designation were tried to be improved priorly for this period. So, first at all, a test cell that 5 cm long and 3.5 cm diameter was made which the meat could be inserted inside it. Then, 3.5 cm diameter electrodes were needed that contact and cover the meat surface in whole (Figure 2.7 and Figure 2.8). Firstly, 304 code number of stainless steel electrodes were tried but they weren't succesfull for cooking. Then, 430 code number of stainless steel electrodes were tried and cooking was very succesfull. For this system, meat was shaped by 3.5 cm diameter sharp cutter (Figure 2.7) and then located into test cell. After that, round stainless steel electrodes were placed to the two open ends of test cell and whole contact was supplied with the meat. Meat pieces were only between two electrodes. While using forks, meat pieces were outside of the forks and uniform cooking could not be achieved. However, in this system homogeneous and uniform cooking of meat was achieved. So, electrode (430 stainless steel) designation was succesfull.

Figure 2.4 Ohmic Cooking System

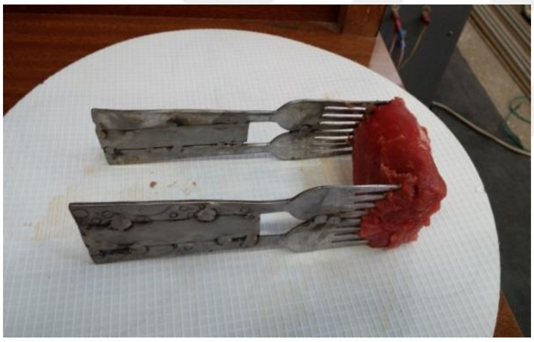

Figure 2.5 Raw meat with forks

Figure 2.6 Ohmic cooked meat with forks

Figure 2.7 Test cell, a meat cutter, 3.5 cm diameter stainless steel electrodes

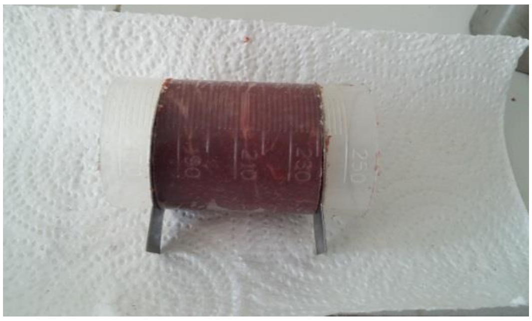

Figure 2.8 Meat inside test cell is ready for ohmic cooking

Many trials were performed for determining appropriate voltage level and treatment time for ohmic cooking as shown in the Figures 2.9 and 2.10. Lower voltage values and treatment times caused under cooked meat samples while higher voltage levels and treatment times caused excessive cooked meat samples and electrode corrosion. 40, 55 and 70 Volt levels were decided and application time was adjusted to 7 minute for ohmic cooking. Ohmic cooking alone, ultrasound-ohmic, ohmic-infrared and ultrasound-ohmic-infrared cooked meat samples were analyzed

Figure 2.9 Ohmic cooking trials for 50 V and 4, 5, 6 and 7 minutes

Figure 2.10 Ohmic cooking trials for 40, 50 and 70 V and 9 minutes

2.6 Infrared Cooking Procedure

Infrared cooking was applied using Frigidaire Professional Stainless Programmable 6-Slice Infrared Convection Oven (Frigidaire, FPCO06D7MS 120V-60 Hz 1500 Toaster Oven, US), (Figure 2.11). In infrared cooking, three different temperatures were used. These were 162.77 °C (325 °F), 190.55 °C (375 °F) and 218.33 °C (425 °F). At infrared cooking alone for the central temperature of beef muscle to reach 72 °C, application time was 12 minutes for each side of meat at 162.77 °C (325 °F), 8 minutes for each side of meat at 190.55 °C (375 °F) and 5 minutes for each side of meat at 218.33 °C (425 °F). At ohmic cooking followed by infrared and hybrid cooking treatments, time of infrared cooking was 3 minutes for each side.

Figure 2.11 Infrared Oven

2.7 Characteristics of Raw and Cooked Systems

Moisture content, pH, color, texture, Total Aerobic Mesophilic Bacteria (TAMB) and Total Coliform (TC) counts, Thiobarbituric Acid Reactive Substance (TBARS) and Polycyclic Aromatic Hydrocarbons (PAH) analyses were performed for raw meat and also for ohmic cooking alone, infrared cooking alone, ultrasound-ohmic, ohmic-infrared and ultrasound-ohmic-infrared (hybrid cooking) cooked meat.

2.7.1 Moisture content

Moisture content of the samples was determined by oven methods (AOAC, 1990) at 105 °C until constant weight was reached.

2.7.2 pH

The pH value of the sample was examined using a pH meter (Jenway 3010; Jenway LTD, Essex, UK) equipped with a J95, 924001 electrode (Jenway LTD, Essex, UK). The measurement of pH value was carried out on 10 g of sample homogenised in distilled water (1/10: sample/water).

2.7.3 Color Analysis

Color measurement (Hunter L*, a*, b*) were made by using a Hunter lab ColorFlex (A60-1010-615 Model calorimeter, Hunter lab, Reston, VA). The instrument was standardized each time with a white and black ceramic plates (Lo = 93.41, a0 = -1.12, and b0= 1.10). The Hunter L*, a*, b* correspond to lightness (L*), greenness (-a*) or redness (+a*), and blueness (-b*) or yellowness, (+b*), respectively. Hue (H) and Chroma (S) were also determined. The color measurements of raw and only ohmic, only infrared, ultrasound-ohmic, ohmic- infrared and hybrid cooked meat samples of both inner and outer surface were performed at room temperature (20 °C ±2) in duplicate for each batch.

2.7.4 Texture Analysis

For texture profile analysis, TPA tests were performed using a TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY/Stable Microsystems, Godalming, UK) to determine hardness (g), adhesiveness (g.s), springiness, cohesiveness, gumminess, chewiness, and resilience. Test conditions were: aluminium circular probe; 5 cm radius; test speed 1 mm/s; pre-test speed 2 mm/s, post-test speed 1 mm/s; compression (strain) 30 %; trigger force 10 g and 25 kg load cell. The texture analysis of raw and hybrid cooked meat samples were performed at room temperature (20 °C ±2).

2.7.5 Total Aerobic Mesophilic Bacteria (TAMB) and Total Coliform (TC) Counts

Total Aerobic Mesophilic Bacteria (TAMB) and Total Coliform (TC) counts were made with the aerobic spread plate count method as described by Bozkurt and Erkmen (2002). For total aerobic count, nutrient agar (Sisco Research Laboratories, India) and for coliform count VRBL (violet red bile with lactose, Conda Laboratorios, Spain) agar was used. A 2 ml of the dilution was transferred into corresponding labeled plate and spread plated over the aerobic plate agar surface. Inoculated agar plates were incubated at 35 °C for 24 hr to 72 hr. Colonies on the agar plates in the range from 30 to 300 colonies were counted. Average value was taken from the duplicate count and then TAMB and TC counts were recorded as total number per g of meat sample.

2.7.6 TBARS (Thiobarbituric Acid Reactive Substance) Analysis

2.7.6.1 Standard Calibration

A standard calibration was prepared using 1,1,3,3-tetramethoxypropane (TMEP). First of all, 166 µl TMEP solution was completed to 1 liter by pure water to prepare stock solution. Then 0.1 ml, 0.2 ml, 0.3 ml, 0.4 ml, 0.5 ml, 0.7 ml and 1.0 ml were taken from stock solution and each of them was completed to 10 ml by pure water. After that, 0.5 ml solution was taken into tubes from each dilution and homogenized with 5 ml 10 % trichloroacetic acid (TCA). Then, homogenized solution was centrifuged for 20 minutes. About 2 ml supernatant was taken and mixed with 2 ml of 1% thiobarbituric acid (TBA). It was placed into 95 °C water bath and waited for 30 minutes. At the end of this period, shock cold was applied to standard samples. Finally absorbance was read at 532 nm against blank and standard curve was obtained using UV-Vis spectrophotometer (SP-3000 Optima, 50/60 Hz, 96 W, Japan).

2.7.6.2 TBARS Determination

TBARS is the most common method for the measurement of lipid oxidation in meat that consists of the spectrophotometric determination of malondialdehyde (MDA) formation as an index of oxidative status. About 1 g of the meat sample was taken and homogenized with 5 ml of 10% TCA. Homogenized solution was centrifuged for 20 minutes. About 2 ml supernatant was taken and mixed with 2 ml of 1% TBA. It was placed into water bath at 95 °C and waited for 30 minutes. At the end of this period, shock cold was applied to standard samples. Finally, absorbance value was read at 532 nm against blank and TBARS values of sample was determined by UV-

Vis spectrophotometer (SP-3000 Optima, 50/60 Hz, 96 W, Japan) using calibration curve.

2.7.7 PAH (Polycyclic Aromatic Hydrocarbons) Analysis

2.7.7.1 Preparation of Standard Solutions

Stock solutions of PAH standard (EPA Method 8310 PAH mixture, Restek) were prepared by dissolving it in ultrapure water (EMD Millipore, Merck KGaA, Germany). First of all, 50 µl PAH standard mixture was completed to 50 ml by ultrapure water. So, 500 ppb concentration of stock solution was ready. Then, one by one 6 ml, 4 ml, 2 ml, 1 ml and 0.5 ml were taken from stock solution and completed each of them to 10 ml by pure water. By this way, 300 ppb, 200 ppb, 100 ppb, 50 ppb and 25 ppb concentrations of stock solutions were made.

2.7.7.2 Sample extraction and clean-up

The procedure of extraction and clean-up were carried out according to the method described by Chung *et al*. (2011) and Kendirci *et al*. (2014). In the round flask of 500 ml, nearly 30 g samples 100 ml KOH (2 M, prepared by using methanol: water (9:1)) solution and 100 ml hexane were added, respectively. The flask was kept in an 80 ± 2 °C water bath under reflux for 2 h. Then, cooling the flask to around 40 °C was realized by the addition of 100 ml cold water and holding it overnight in the dark. Hexane phase was moved into 250 ml erlenmayer flask and condensed to 2 ml at 50 ± 2 °C using a vacuum oven. The concentrate was purified by transferring into a Sep-Pak florisil cartridge (Vac C18 6 cc, Waters Corporation, USA), which had been pre-conditioned with 10 ml dichloromethane and 20 ml hexane. Elution solvents involving 10 ml hexane and 8 ml hexane:dichloromethane (3:1) were moved through the cartridge, respectively. All the eluates were collected, dissolved in 1 ml of acetonitrile, filtered through 0.45 µm membrane filter (Minisart RC 25, Germany) and collected into 2 ml amber vials.

2.7.7.3 PAH determination

PAH analysis was carried out by use of an ultra-performance liquid chromatography fluorescence detector (UPLC-FD, RF 20A, Shimadzu, Japan). A Pinnacle-II PAH 4 μm column (Restek LC columns, 50 × 3.2 mm, USA) was used. The gradient solvent system was started with 50% acetonitrile in water (v/v) and linearly increased to 100% acetonitrile within 30 min at a flowrate of 0.5 ml/min. The excitation and emission wavelengths were 360/460 nm. The external calibration curves of the PAHs were prepared by injecting 10 μl working solutions of the standards to UPLC-FD. For quantification of the PAHs, 10 μl sample extract was injected into UPLC-FD.

2.8 Statistical Analysis

Three, two and one way ANOVA were performed for moisture content, pH, color, texture, TAMBC, TCC, TBARS and PAHs as a function of cooking parameter to determine significant differences ($P<0.05$) using the SPSS version 21.0 (SPSS Inc., Chicago, IL, USA). Duncan's multiple range test was also carried out during the cooking process for analysing homogeneous groups. Cooking system was performed in triplicate and all analyses were replicated two times. Trends were considered as significant when the means of compared parameters differed at a $P < 0.05$ significance level.

CHAPTER III

RESULTS AND DISCUSSIONS

3.1 Moisture Content

Moisture content of cooked samples is important because it reflects both the taste and the toughness level since insufficiently cooked patties will be moist, while overcooked patties will be tough (Özkan et al., 2004). In this study, moisture content of ohmic, infrared, ultrasound-ohmic, ohmic-infrared and ultrasound-ohmic-infrared cooked beef samples were determined after the cooking process (Figures 3.1 - 3.4). The change in moisture content values and statistical analysis results (one way ANOVA) are shown in the Tables 3.1 - 3.4.

Ultrasound treatment was performed at three different time which were 10, 20 and 30 minutes. 40, 55 and 70 Volt levels were used and application time was adjusted to 7 minute for ohmic cooking. At ohmic cooking followed by infrared and consecutive application of ultrasound, ohmic and infrared cooking (hybrid cooking) treatments, time of infrared cooking was 3 minutes for each sides of meat during cooking.

Ohmically cooked beef samples were significantly ($P<0.05$) different from raw meat with respect to moisture content. However, at ohmic cooking alone, increasing the voltage level did not cause a significant difference on moisture content value of beef meat (Table 3.1). Voltage gradient is reported to be a significant ($P<0.05$) variable in ohmic process (İçier and Ilicali 2004). In ohmic process, heat is generated instantly inside of the food. Electrical conductivity of the food material and inducing current which is caused by the voltage level affects the generation of heat quantity. There are some studies in the literature that shows the effect of voltage gradient on ohmic cooking process of different foods. Heating rates were found to increase sharply with increasing voltage gradients (Palaniappan and Sastry, 1991a). It has been shown that the osmotic pressure across a straight capillary media was directly proportional to the voltage gradient (Crow, 1988). The application of voltage causes fluid motion through the capillary porous membranes of the biological tissue. Crow (1979) reported that when applying a few volts to electrolytic solutions, there was no measurable variation in electrical conductivity with voltage gradient. However, at 100 kV/cm, some differences may be observed. Palaniappan and Sastry (1991b) reported no effect of voltage gradient (30–60V/cm) on the electrical conductivity of orange juice. Palaniappan and Sastry (1991a) applied a higher voltage gradient of 60 V/cm to potato, carrot, chicken, and lean beef samples and reported a decrease in the electrical conductivity as voltage gradient decreased. Icier and Bozkurt (2010) studied the cooking of beef samples having different fat content (2%, 9% and 15 %) ohmically (20, 30 and 40 V/cm) and conventionally. They reported that voltage gradient applied ohmic cooking did not affect the quality parameters such as moisture content, firmness and thoughness of samples.

Table 3.1 Moisture content values of ohmically cooked beef meat

Ohmic Cooking (Volt)	Moisture Content (%)
Raw meat	74.61±0.66^{a}
40	64.02±0.36^{b}
55	63.14±0.58^{b}
70	62.74±0.85^{b}

Different small letters; a, b, c indicate statistical difference between voltage gradient values of ohmic cooking at α=0.05 level

Infrared cooking alone was performed until the internal core temperature of meat reached to 72°C. At infrared cooking alone, time duration was 12 minutes for each sides of meat at 162.77 °C (325 °F), 8 minutes for each sides of meat at 190.55 °C (375 °F) and 5 minutes for each sides of meat at 218.33 °C (425 °F). At infrared cooking, infrared energy is transmitted as a wave and is absorbed by the beef muscle; interactivity of the beef molecules stimulates the conversion of energy into heat. Permeability of infrared energy greatly influences the quality of beef during a heating process. Higher infrared temperature leads to higher energy permeation into beef muscle and rapid heating which caused to release of water easily (Sun, 2006).

Moisture content value of raw meat and infrared cooked beef meat samples were shown in Table 3.2. In this study infrared cooking caused a significant difference on moisture content of beef meat compared to raw beef meat. However, increase in infrared temperature did not affect the moisture content value of beef meat significantly (P>0.05). This could be due to shortening of cooking time while increasing cooking temperature to be able to reach 72 °C core temperature in beef meat. Datta and Ni (2002) reported that infrared can reduce surface moisture of foods especially when absorbed on the surface.

Table 3.2 Moisture content values of infrared cooked beef meat

Infrared Cooking (°F) (core temp. 72 °C)	**Moisture Content** (%)
Raw meat	72.29 ± 2.25^{a}
325	64.32 ± 2.98^{b}
375	65.82 ± 1.10^{b}
425	65.68 ± 2.20^{b}

Different small letters; a, b, c indicate statistical difference between infrared cooking temperature values at α=0.05 level

At consecutive application of ultrasound treatment with ohmic cooking, it would be better to see how ultrasonic treatment affects the performance of ohmic processing. According to two way ANOVA results, the interaction of ultrasound and ohmic treatment did not cause a significant effect on moisture content of meat (P>0.05). According to one way ANOVA results, at 40, 55 and 70 volt ohmic cooking, the increase of ultrasound treatment did not cause a significant effect (P>0.05) on moisture content of meat (Table 3.3). At 10 minutes ultrasound treatment, increase of voltage value caused to decrease moisture content significantly (P<0.05). However, at 20 and 30 minutes ultrasound treatment, increase in voltage value did not cause a significant effect (P>0.05) on moisture content of meat (Table 3.4). Meat has higher moisture content and heteregoneus structure. Ultrasound assists cooking and helps ohmic cooking to be more effective. However, ohmic cooking followed by ultrasound pretreatment was effective to decrease the moisture content of beef only 10 minute ultrasound application before 40 V, 55 V and 70 V. As it is understood from this result, application of higher ultrasound pretreatment time should not be required for increasing ohmic cooking effectiveness on moisture content of beef muscle.

Table 3.3 Moisture content values of ultrasound- ohmic cooked meat at constant ohmic voltage level

Ultrasound (min.)	Ohmic (Volt)	Moisture Content %
0	untreated	74.22±2.79[a]
10	40	63.23±0.84[b]
20		63.35±0.11[b]
30		60.12±1.95[b]
0	untreated	74.22±2.79[a]
10	55	59.71±1.42[b]
20		59.85±0.71[b]
30		59.88±0.21[b]
0	untreated	74.22±2.79[a]
10	70	56.75±0.67[b]
20		57.11±5.91[b]
30		59.30±0.31[b]

Different small letters; a, b, c indicate statistical difference between ultrasound treatment time values at each same voltage gradient at α=0.05 level

Table 3.4 Moisture content values of ultrasound-ohmic cooked meat at constant ultrasound time

Ultrasound (min.)	Ohmic (Volt)	Moisture Content %
0	untreated	74.22±2.79[a]
10	40	63.23±0.84[b]
	55	59.71±1.42[bc]
	70	56.75±0.67[c]
0	untreated	74.22±2.79[a]
20	40	63.35±0.11[b]
	55	59.85±0.71[b]
	70	57.11±5.91[b]
0	untreated	74.22±2.79[a]
30	40	60.12±1.95[b]
	55	59.88±0.21[b]
	70	59.30±0.31[b]

Different small letters; a, b, c indicate statistical difference between voltage gradient values at each same ultrasound treatment time at α=0.05 level.

At consecutive application of ohmic cooking with infrared treatment, moisture content values of beef were in the range between 59.30 and 74.22%. According to two way ANOVA results, ohmic cooking followed by infrared treatment did not cause a significant effect on moisture content of meat (P>0.05) as it was in the ultrasound-ohmic interaction. According to one way ANOVA results, at 40 Volt ohmic treatment, increase in infrared temperature from 325 °F to 375 °F caused to decrease moisture content significantly (P<0.05), however, increase in infrared temperature 375 °F to 425 °F did not cause a significant effect on moisture content of meat (P>0.05). This could be due to penetration of moist materials by radiation to some depth was achieved up to 375 °F for constant 40 V ohmic cooking. As shown in Figure 3.1, at 55 and 70 V ohmic cooking treatment, increasing infrared temperature did not cause a significant effect on moisture content of meat (P>0.05). As shown in Figure 3.2, at 325 °F, the increase in voltage value decreased moisture content of meat significantly, but at 375 and 425 °F increase in voltage value did not cause a significant effect on moisture content of meat. Infrared radiation energy driving internal moisture movement during cooking (Krishnamurthy et al., 2008). Sakai and Hanzawa (1994) argued that most infrared radiation energy is absorbed on the surface of a food system is related to the predominant energy absorption of water. Energy would be transported by conductive heat transfer in the food. Generally, infrared radiation is absorbed by solid materials in a thin surface layer. However radiation penetrates moist porous materials to some extent and their transmissivity depends on the moisture content (Lampinen et al., 1991).

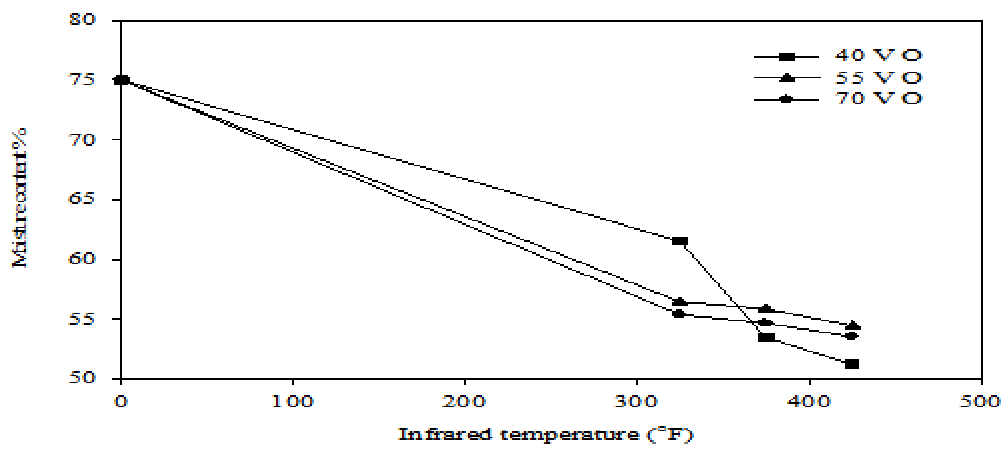

Figure 3.1 Moisture content values of ohmic-infrared cooked meat at constant ohmic voltage. Abbreviations: V: Volt; O: Ohmic

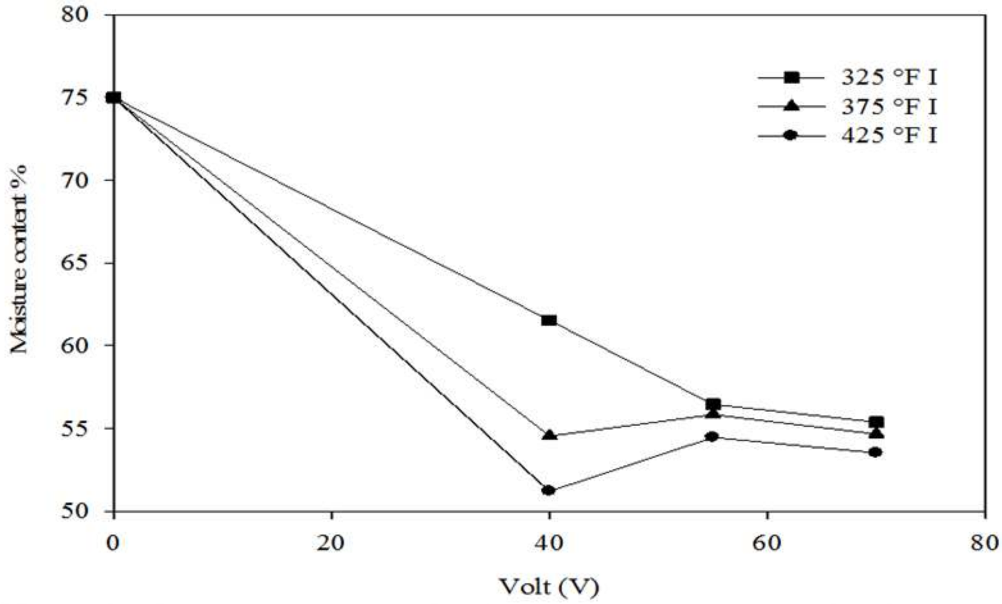

Figure 3.2 Moisture content values of ohmic-infrared cooked meat at constant infrared temperature. Abbreviations: °F: Fahrenheit Degree; I: Infrared.

Moisture content values of hybrid cooking consisting of a consecutive application of three techniques which were ultrasound, ohmic and infrared treatments. Moisture content values of hybrid system are shown in the Figures 3.3 and 3.4. Moisture content value of raw beef meat was found as 72.40% while hybrid-processed meat moisture content values were in the range between 51.01 and 66.48 %. The lowest moisture content value was reached at the highest ultrasound time (30 min.), highest ohmic voltage level (70 V) and highest infrared temperature (425 °F). Three way ANOVA results showed that ultrasound, ohmic and infrared interaction did not cause a significant effect on moisture content of meat ($P>0.05$). However ultrasound, ohmic and infrared treatment, seperately had a significant effect on moisture content of beef muscle ($P<0.05$). In this hybrid system, the interaction of ultrasound-ohmic , ultrasound - infrared treatments did not affect moisture content of beef significantly ($P>0.05$), however the interaction of ohmic - infrared treatment had significant effect on moisture content of beef ($P<0.05$) since infrared radiation provides high surface temperature within a minute and releases more water and this migrates outwards (and Sheridan and Shilton, 2002).

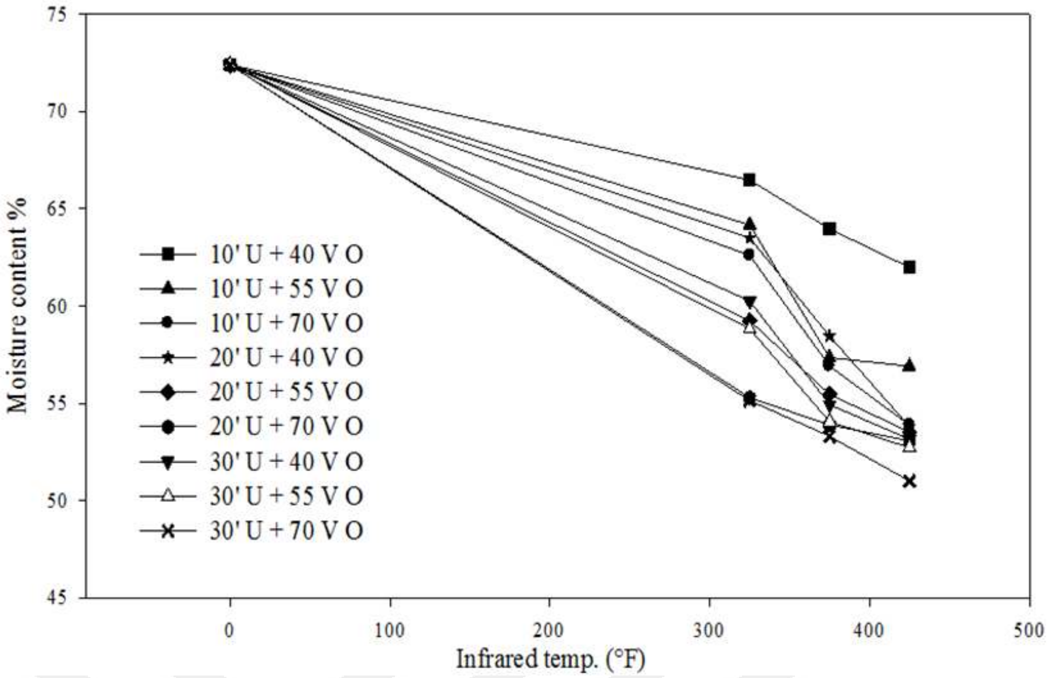

Figure 3.3 Moisture content values of ultrasound-ohmic-infrared cooked meat at constant ultrasound time and ohmic voltage level. Abbreviations: ': minute; U: Ultrasound; V: Volt; O: Ohmic

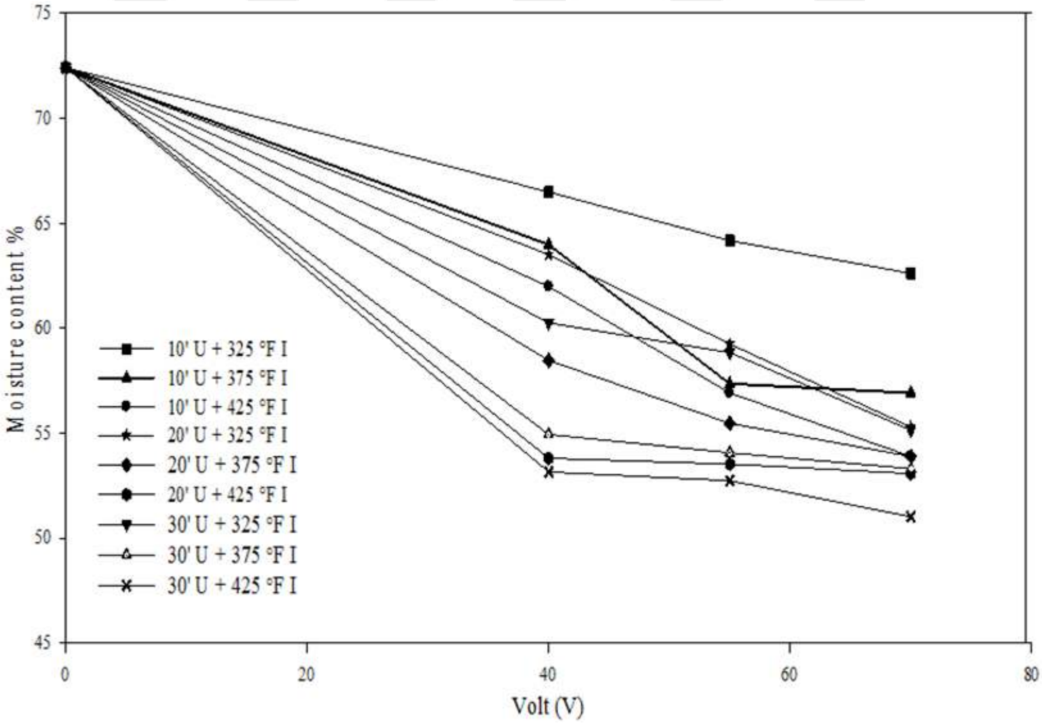

Figure 3.4 Moisture content values of ultrasound-ohmic-infrared cooked meat at constant ultrasound time and infrared temperature. Abbreviations: ': minute; U: Ultrasound; °F: Fahrenheit Degree; I: Infrared

Meat is a food that includes higher moisture content and it shows a higher electrical conductivity during ohmic heating. It has been reported that, as more water molecules are present in the medium, it is possible for ionic mobility to increase (Ramaswamy et al., 2014). There are some studies that shows the combined effect of ohmic cooking with other cooking techniques on moisture content of foods. Cho et al. (1996) designed a hydraulic press integrated with an ohmic heating system in order to remove water from soybean milk residues. The moisture content of residue after the water removal was 74% in conventional hydraulic press however it was possible to reduce the moisture content down to 70% using the ohmic heating press. Application of an alternating current of 5 Hz at 60 V maximized the efficiency of water removal process. Özkan et al. (2004) studied the cooking of hamburger patties by the ohmic and plate heating combination method and results were subjected to quality analyses and compared with normal grill plates cooked samples. Ohmic cooking was carried out at 50 V in that study. The results obtained from the quality tests indicated that the mechanical properties, moisture or fat content of the cooked hamburger was not significantly affected by the use of ohmic cooking.

As a consequence, lower moisture content values of cooked beef muscles were obtained in hybrid system, especially at higher ultrasound time, higher ohmic voltage gradient and higher infared temperature treatments in comparison with moisture content values reached at ohmic cooking alone, infrared cooking alone, ultrasound-ohmic and ohmic-infrared treatments. Ultrasound treatment distrupts the myofibrillar structure of meat. Ohmic processing after the ultrasound treatment, the water in meat vaporized and removed more easily. Infrared treatment following the ohmic cooking provided the fastly desiccation of meat. This could be understood that hybrid system composed a synergistic cooking effect by lowering moisture content which indicates the safety of beef.

3.2 pH

pH analyses of beef meat were performed for only ohmic, only infrared, ultrasound - ohmic, ohmic - infrared and ultrasound - ohmic - infrared cooking. In this study, as it was seen in the Tables 3.5 - 3.8 and Figure 3.5, the pH value of raw beef meat was measured in the range of 5.42 and 5.65.

At ohmic cooking alone process, pH values were ranged between 5.49 and 5.94. Voltage increment to 40 and 55 V caused a significant increase in pH value of beef meat, however voltage increment from 55 to 70 V did not cause a significant effect on pH value of beef meat (Table 3.5). This could be due to corrosion of electrodes that might occur during the 70 V ohmic cooking. İçier and Bozkurt (2010) studied the cooking of beef samples having different fat contents (2, 9, 15 %) by ohmic heating (20, 30 and 40 V/cm) and investigated the effect of voltage gradient on some quality parameters of ground beef. They found pH values of raw meat as 5.14 and ohmically cooked meat samples as in the range of 5.35-5.93 which were lower than our study. They observed ohmically cooked beef sample pH values were significantly different from raw beef sample pH values as it is in our study, but voltage gradient had no significant effect on pH value. Sengun et al. (2014) also determined the effect of ohmic cooking (15.26 V) on some quality attributes of semi-cooked meatballs. It was observed that the pH value of meatball increased by ohmically cooking. Another challenge study performed by Darvishi et al. (2012) is the investigation of the effect of ohmic heating technique on electrical conductivity, heating rate, system performance and pH of pomegranate juice. They observed that the voltage gradient (30-55 V) had significant effect on the pH change of pomegranate juice samples during ohmic treatment.

Table 3.5 pH value of ohmic cooked beef

Ohmic Cooking (Volt)	**pH**
Raw meat	5.49 ± 0.01^{a}
40	5.73 ± 0.05^{b}
55	5.85 ± 0.04^{c}
70	5.94 ± 0.02^{c}

Different small letters; a, b, c indicate statistical difference between voltage gradient values of ohmic cooking at $\alpha=0.05$ level

At infrared cooking alone process, pH values of beef muscle were ranged between 5.42 and 5.71. The increase of temperature (325 and 375 °F) caused to increase of pH values of beef meat but at 425 °F pH value of beef meat decreased (Table 3.6). Laakkonen et al. (1970) investigated the effect of low temperature, long time heating on tenderness, water holding capacity on bovine muscle and they examined that the pH values of meat gradually increased during heating.

Table 3.6 pH value of infrared cooked beef

Infrared Cooking (°F) (core temp. 72 °C)	**pH**
Raw meat	5.42±0.04[a]
325	5.57±0.07[b]
375	5.71±0.08[d]
425	5.63±0.09[c]

Different small letters; a, b, c indicate statistical difference between infrared cooking temperature values at α=0.05 level

At consecutive application of ultrasound treatment with ohmic cooking, at constant voltage levels of 40, 55 and 70 V, the increase of ultrasound time did not cause a significant effect on pH value of beef muscle (Table 3.7). Stadnik et al. (2008) investigated the potential of low frequency and relatively low-intensity ultrasound (45 kHz, 2W/cm^2) treatment at 24 h in affecting the post-mortem pH of meat and its water-holding capacity during 96 h of meat ageing. Their study revealed that ultrasound treatment did not have a significant effect on the pH of the meat.

Table 3.7 pH value of ultrasound-ohmic cooked beef

Ultrasound (min.)	**Ohmic (Volt)**	**pH**
0	untreated	5.65±0.07[a]
10	40	5.85±0.04[b]
20		5.88±0.02[b]
30		5.90±0.02[b]
0	untreated	5.65±0.07[a]
10	55	5.94±0.05[b]
20		5.97±0.07[b]
30		5.96±0.04[b]
0	untreated	5.65±0.07[a]
10	70	5.90±0.04[bc]
20		5.81±0.05[b]
30		5.96±0.02[c]

Different small letters; a, b, c indicate statistical difference among ultrasound treatment time values at each same voltage gradient at α=0.05 level

At consecutive application of ohmic and infrared cooking, pH values were in the range between 5.50 and 6.02. At 40 and 55 V ohmic voltage level, with increasing infrared temperature, pH value firstly increased then decreased. However at 70 V ohmic voltage level, the increase of infrared temperature caused a significant increase ($P<0.05$) in pH value of beef muscle (Table 3.8). The increase in pH may be attributed to the loss of free acidic groups (Lawrie, 1979). Tilgner (1958) stated that on cooking at temperatures above 80 °C, free hydrogen sulphide begins to form and increases with increasing temperature.

Table 3.8 pH value of ohmic-infrared cooked beef

Ohmic Cooking (Volt)	Infrared Cooking (°F)	pH
0	untreated	5.50 ± 0.12^{a}
40	325	5.78 ± 0.09^{c}
	375	5.62 ± 0.08^{b}
	425	5.70 ± 0.07^{bc}
0	untreated	5.50 ± 0.12^{a}
55	325	5.85 ± 0.08^{c}
	375	5.71 ± 0.07^{b}
	425	5.94 ± 0.05^{c}
0	untreated	5.50 ± 0.12^{a}
70	325	5.81 ± 0.07^{b}
	375	5.91 ± 0.08^{c}
	425	6.02 ± 0.11^{d}

Different small letters; a, b, c indicate statistical difference among infrared temperature values at each same voltage gradient at α=0.05 level

At consecutive application of ultrasound, ohmic and infrared treatment, pH values were ranged between 5.45 and 5.92 (Figure 3.5). At constant ultrasound time and infrared temperature, the increase of voltage gradient did not cause a significant difference ($P > 0.05$) on pH value of 10 min. ultrasound- 325 °F infrared, 10 min. ultrasound- 425 °F infrared, 30 min. ultrasound- 325 °F infrared treatment. However, the rest of the constant ultrasound time and infrared temperature treatments, as a general, increase of voltage gradient caused a significant increase ($P < 0.05$) on pH value. At higher voltage gradients, the current passing through the sample was higher which could caused to measure higher pH.

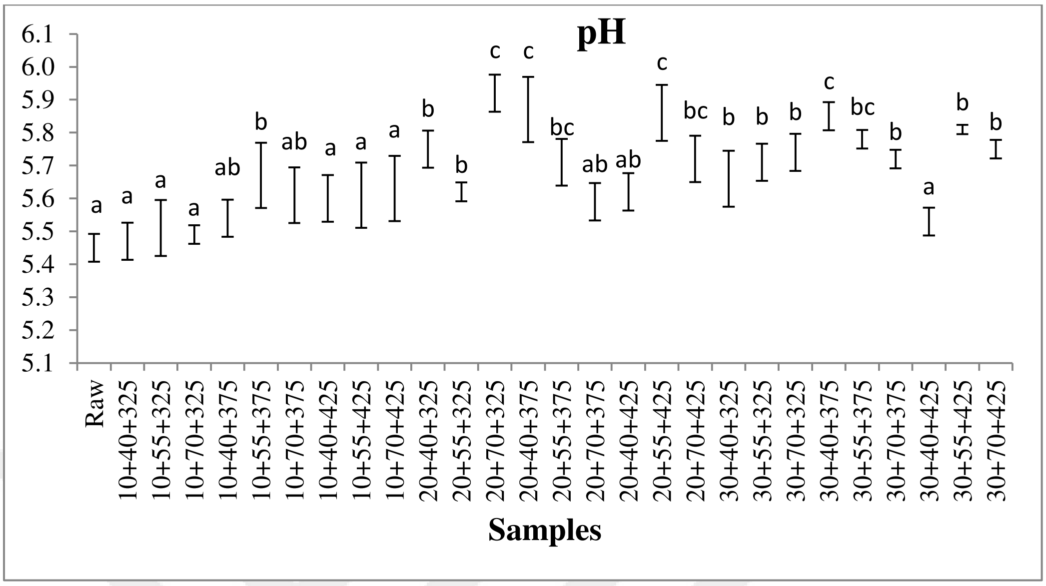

Figure 3.5 pH value of ultrasound-ohmic-infrared cooked beef

Different small letters; a, b, c indicate statistical difference between voltage gradient values of ultrasound-ohmic-infrared cooking at each constant ultrasound time and infrared temperature (α=0.05 level). Samples are indicated by three numbers; first represents the ultrasound time in minute, second represents the ohmic voltage level and third represents the infrared temperature value.

3.3 Color

Color of cooked meat product is one of the important parameter for the consumer preferences and also for the shelflife. Moreover, its measurement can provide reliable information about eating quality attributes. In raw meat and meat products the desired colour is usually the bright red oxymyoglobin. In cooked meat and meat products the desired colour is usually the brown denatured globin haemichrome (Ranken et al., 2000). The color of beef changes from a deep red to a pinkish gray during the cooking process and finishes as light brown (Kondjoyan et al., 2014). Color analysis (L*, a*, b*, H and S) of ohmic, infrared, ultrasound-ohmic, ohmic-infrared, ultrasound-ohmic-infrared cooked samples were followed during the process (Figure 3.6–3.11; Table 3.9–3.14). Color measurements were performed on both inside and outside surfaces of the cooked sample.

At ohmic cooking alone process, L*inner values were in the range between 20.69 and 33.93 while L*outer values ranged from 32.56 to 46.51. As it was seen in the Figure 3.6, the outer surface had higher lightness value than inner surface lightness value of beef samples. Both surface (L*outer, a*outer, b*outer) and centre color (L*inner, a*inner, b*inner) values of cooked beef samples were significantly different ($P<0.05$) from raw beef sample. These results were in aggrement with the study of İçier and Bozkurt (2010) in the literature. They studied the cooking of beef samples having different fat contents (2, 9, 15 %) ohmically (20, 30 and 40 V/cm) and found L* values in the range of 36.36- 48.19. Moreover, Shirsat et al. (2004) investigated the steam and ohmic cooking of meat emulsion samples (3, 5 and 7 V/cm). However, in that study, L* values were found as 67.78-69.82 which were very higher values comparing to our study. This could be due to using higher voltage gradients in our study and this situation showed favorable effect on heating rate. Therefore lower L* values namely brown beef samples were obtained in our study. At ohmic cooking alone process, the increase of voltage level 0 to 40 V caused to increase of L*inner value of beef meat however increase of voltage level 40 to 55 V and 55 to 70 V caused to decrease of L* inner value. The increase of voltage level caused to decrease of L*outer value. The decrease of lightness value illustrated decreasing of the lightness and dark color formation due to the browning reaction. The increase of voltage level caused to decrease of a* value of ohmic cooked beef insignificantly ($P>0.05$). Decrease of a* values represented reduction of reddish and an increase in brownish-red and greenish (metmyglobin and sulfmyglobin species). The increase of voltage level firstly caused to increase of b* value then caused to decrease it as in the L* inner value (Figure 3.6).

Hue angle (H) is the most appropriate combination color property, which described the total color changes of the meat samples during cooking process (Ulu, 2004). H values for both inside and outside surfaces of ohmically cooked beef samples were significantly different ($P<0.05$) from raw beef samples. However, voltage increment had no significant effect on H values for both inside and outside surfaces of beef samples ($P>0.05$) (Table 3.9). İçier and Bozkurt (2010) also found that voltage gradient did not affect the H value significantly ($P>0.05$).

Chroma (S) is the quality of color purity, intensity and saturation. S values for inside of beef samples were ranged between 14.67 and 6.58 whereas S values for outside of beef muscle were ranged between 13.73 and 14.67 (Table 3.9) which were close to the S results (14.26 to 14.19) of the study that ohmic cooked beef samples at voltage densities ranging from 3 to 7 V/cm carried out by Shirsat et al. (2004). In the present study, the increase of voltage gradient caused to decrease of S value for inside of beef samples significantly. However, S values for outside of beef muscles were not affected significantly (P>0.05) by the voltage gradient.

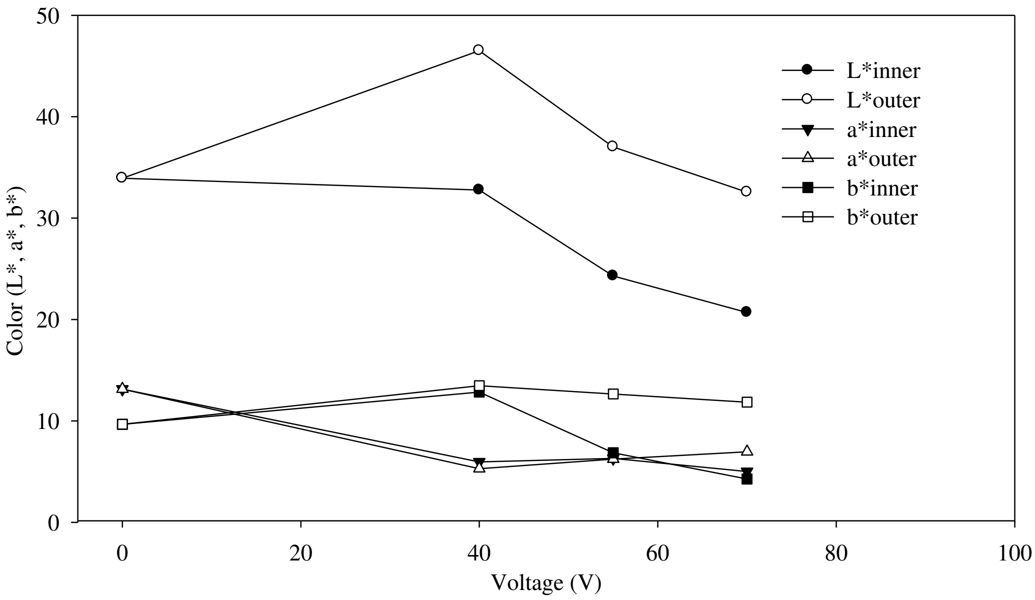

Figure 3.6 Color (L*, a*, b*) values of ohmically cooked meat

Table 3.9 Color (Hue and Chroma) values of ohmically cooked meat

Ohmic Cooking (V)	Hue inner	Hue outer	Chroma inner	Chroma outer
Raw meat	40.77±4.87[a]	40.77±4.87[a]	14.67±0.90[a]	14.67±0.90[a]
40	60.17±3.78[b]	68.58±4.20[b]	12.03±1.04[b]	14.48±0.03[a]
55	47.45±2.87[a]	63.32±4.00[b]	9.31±0.37[c]	14.11±3.19[a]
70	40.47±2.30[a]	59.51±2.41[b]	6.58±0.20[d]	13.73±0.75[a]

Different small letters; a, b, c indicate statistical difference between voltage gradient values of ohmic cooking at α=0.05 level

At infrared cooking alone process, L*inner values were in the range between 32.17 and 50.80 and L*outer values were in the range between 25.61 and 35.38 (Figure 3.7). On the contrary of ohmic cooking, at infrared cooking alone process L*outer values were lower than L*inner values. Generally solid materials like beef meat absorb infrared radiation in a thin surface layer (Krishnamurthy et al., 2008). That is why, outer surface color of beef samples were brown than inner surface color of beef samples at infrared cooking alone process. At infrared cooking alone process, increase of temperature had significant effect ($P<0.05$) on L*inner and L*outer values of beef muscle as shown in Figure 3.7. Huang (2004) also indicated that turkey samples were slightly darker which were treated by infrared heating than that of the controls. Inner and outer values of a* and b* of beef muscle did not have a significant difference ($P>0.05$) by increasing infrared temperature. This could be due to shortening of process time at high infrared temperature. Furthermore, infrared radiation can be considered as surface treatment and penetration depth of infrared radiaton into sample is restricted.

H values for both inside and outside and S value for outside surfaces of infrared cooked beef samples were significantly different ($P<0.05$) from raw beef samples (Table 3.10). Temperature increment from 325 °F to 375 °F and 375 °F to 425 °F had no significant effect on both H and S values for outside surfaces of infrared cooked beef samples ($P>0.05$). However, temperature increment from 375 °F to 425 °F caused a significant effect on inside surfaces of H and S values ($P<0.05$). Dostie et al. (1989) indicated that combined application of infrared and convection methods resulted to be more efficient in terms of heating over infrared or convective alone.

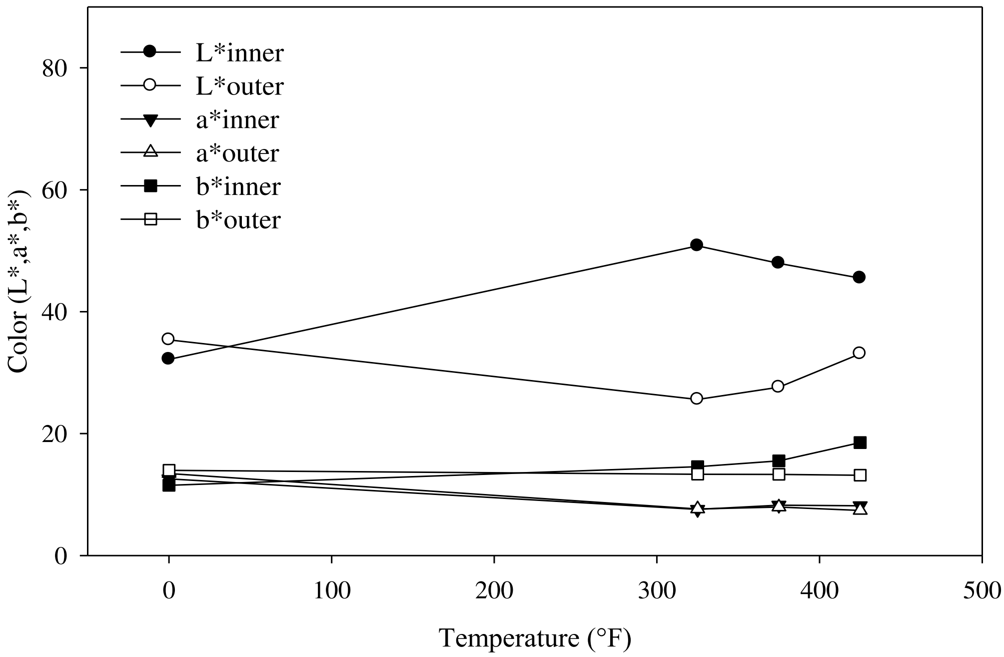

Figure 3.7 Color (L*, a*, b*) values of infrared cooked meat

Table 3.10 Color (Hue and Chroma) values of infrared cooked meat

Infrared Cooking (°F)	Hue inner	Hue outer	Chroma inner	Chroma outer
Raw meat	42.48±0.67[a]	46.08±0.63[a]	17.04±1.85[a]	19.40±0.26[a]
325	62.65±2.87[b]	60.32±3.19[b]	16.44±1.25[a]	15.38±1.33[b]
375	61.97±1.59[b]	59.36±6.12[b]	17.58±0.19[a]	15.54±1.26[b]
425	51.19±3.37[c]	60.42±4.25[b]	23.74±2.11[b]	15.12±1.85[b]

Different small letters; a, b, c indicate statistical difference between infrared cooking temperature values at $\alpha=0.05$ level

At consecutive application of ultrasound treatment with ohmic cooking, L*inner values were ranged between 23.28 and 52.52 while L*outer values were ranged between 26.09 and 51.93. L*inner and L*outer values of cooked beef samples firstly increased then decreased significantly (P<0.05) at each constant voltage gradient by increasing ultrasound process time. The increase of lightening at first could be due to an increase in reflection of light arising from light scattering due to evaporation of moisture and then, the decrease of lightening could be due to increase of brown pigments by longer ultrasound treatment. The lowest L*inner value (38.59), in other words darker beef samples during cooking process were obtained by increasing ultrasound time 10 to 20 min. at constant 55 V ohmic cooking. The lowest L*outer value of beef sample was obtained as 34.67 by increasing ultrasound time 20 to 30 min. at constant 55 V ohmic cooking. Ultrasound treatment was influential to increase the effectiveness of ohmic cooking here. As it can be seen in the Figures 3.8 and 3.9, inner and outer values of a* and b* of beef muscle were not significantly different (P>0.05) by increasing ultrasound time. This could be due to in ultrasound treatment a lower rise of temperature cause to insufficient heat generation for thermal denaturation and oxidation of the colour pigment myoglobin into metmyoglobin (Martens et al., 1982). Jayasooriya et al. (2007) also indicated that ultrasound treatment did not affect any of the CIE (Commission Internationale de l'Elcairage) color parameters (L*,a*,b*). When H and S values are examined, at constant 40 V ohmic cooking, the increase of ultrasound treatment time did not cause a significant effect (P>0.05) on H and S values for both inside and outside surfaces of beef muscles. However at constant 55 V ohmic cooking, the increase of ultrasound treatment time caused a significant decrease ($P<0.05$) on H values for both inside and outside and increase on S value for inside surfaces of beef muscle. At constant 70 V ohmic cooking, the increase of ultrasound treatment time had no significant effect ($P>0.05$) on inner values of H and S values but had significant decrease on outer values of H and S values at 30 min. ultrasound treatment (Table 3.11).

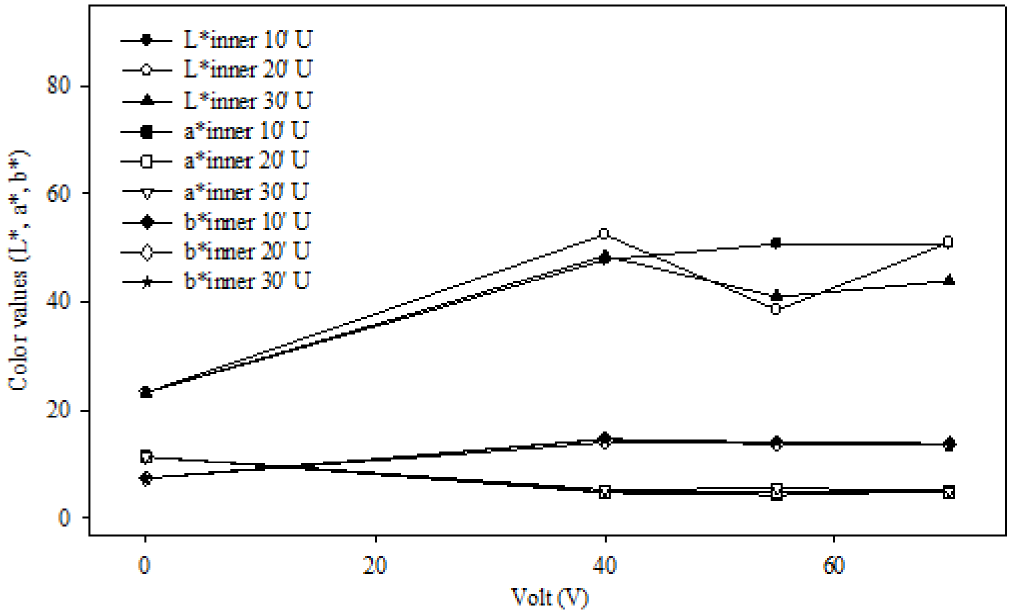

Figure 3.8 Inner surface color (L*, a*, b*) values of ultrasound-ohmic cooked meat. Abbreviations: ': minute; U: Ultrasound

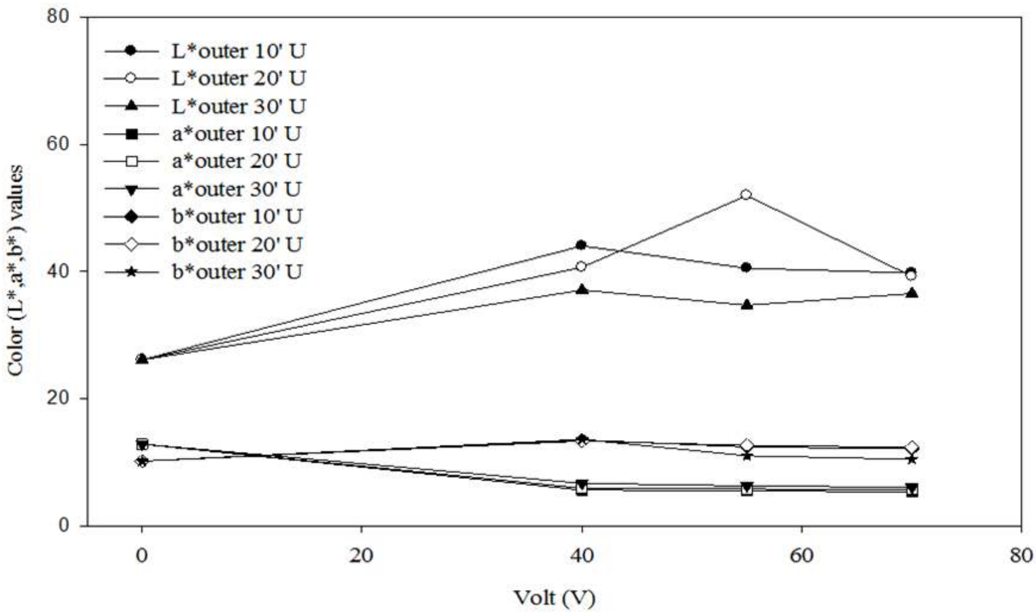

Figure 3.9 Outer surface color (L*, a*, b*) values of ultrasound-ohmic cooked meat. Abbreviations: ': minute; U: Ultrasound

Table 3.11 Color (Hue and Chroma) values of ultrasound-ohmic cooked meat

Ultrasound (min.)	Ohmic (Volt)	Hue inner	Hue outer	Chroma inner	Chroma outer
0	untreated	32.99±0.35^{a}	38.28±0.07^{a}	13.66±0.15^{a}	16.33±0.23^{a}
10	40	71.96±0.12^{b}	67.48±0.38^{c}	15.47±0.05^{c}	14.58±0.66^{b}
20		70.73±0.21^{b}	66.10±1.47^{bc}	14.91±0.16^{b}	14.54±0.77^{b}
30		70.04±2.53^{b}	63.85±0.64^{b}	15.58±0.25^{c}	15.10±0.43^{ab}
0	untreated	32.99±0.35^{a}	38.28±0.07^{a}	13.66±0.15^{a}	16.33±0.23^{a}
10	55	72.80±0.02^{d}	65.77±0.59^{c}	14.66±0.00^{b}	13.54±1.82^{b}
20		70.52±1.25^{c}	65.46±0.43^{c}	14.69±0.19^{b}	13.87±0.23^{ab}
30		68.30±0.16^{b}	60.49±0.58^{b}	15.19±0.24^{c}	12.63±0.22^{b}
0	untreated	32.99±0.35^{a}	38.28±0.07^{a}	13.66±0.15^{a}	16.33±0.23^{a}
10	70	69.74±0.07^{b}	66.65±1.35^{c}	14.80±0.00^{a}	13.17±0.13^{b}
20		70.48±3.17^{b}	65.26±1.10^{c}	14.56±2.27^{a}	13.56±0.56^{b}
30		69.17±1.06^{b}	59.91±0.20^{b}	14.52±0.38^{a}	12.04±0.02^{c}

Different small letters; a, b, c indicate statistical difference among ultrasound treatment time values at each same voltage gradient at α=0.05 level

At consecutive application of ohmic and infrared cooking process, as a general color values of outer surface were lower than inner surface (Figure 3.10). As indicated before, infrared cooking is effective for surface heating of the food samples. Increment of infrared temperature at each constant voltage gradients caused no significant differences on a*, b* and S values of beef muscle. At constant 70 V ohmic treatment, the increase of infrared temperature caused to increase the H value

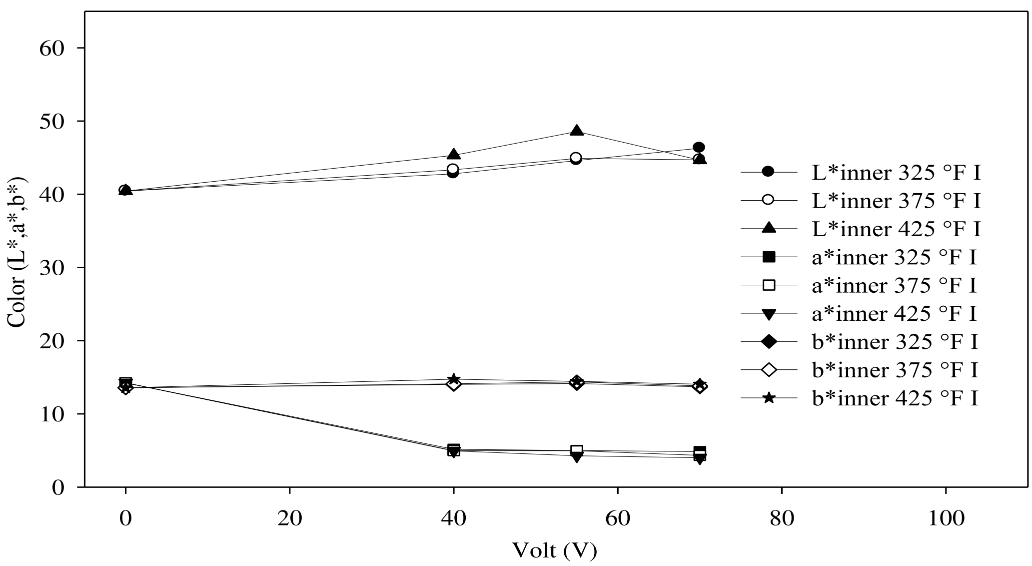

Figure 3.10 Inner surface color (L*, a*, b*) values of ohmic-infrared cooked meat Abbreviations: °F: Fahrenheit Degree; I: Infrared.

significantly for inside surface of beef muscle. Increasing infrared temperature caused to decrease the L*outer value significantly (P<0.05). This is in agreement with Dagerskog and Sorenfors (1978) who stated that only lightness values (L*) of the crust are necessary to observe color change.

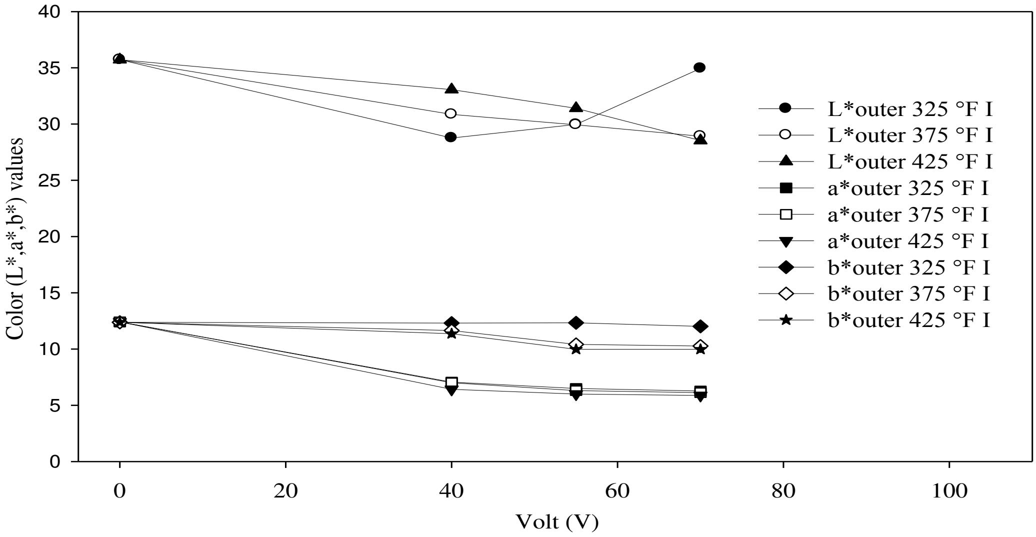

Figure 3.11 Outer surface color (L*, a*, b*) values of ohmic-infrared cooked meat Abbreviations: °F: Fahrenheit Degree; I: Infrared.

Table 3.12 Color (Hue and Chroma) values of ohmic- infrared cooked meat

Ohmic (Volt)	Infrared (°F)	Hue inner	Hue outer	Chroma inner	Chroma outer
0	untreated	43.57±0.09[a]	44.89±1.63[a]	19.67±0.18[a]	17.53±0.61[a]
40	325	69.80±1.54[b]	60.06±4.85[b]	14.94±0.29[b]	14.21±0.56[b]
	375	71.27±0.74[b]	58.94±0.04[b]	15.18±0.48[b]	13.58±1.82[b]
	425	70.67±0.89[b]	60.39±1.59[b]	14.96±0.24[b]	13.05±1.79[b]
0	untreated	43.57±0.09[a]	44.89±1.63[a]	13.58±1.82[b]	17.53±0.61[a]
55	325	71.26±0.15[b]	62.12±1.80[b]	13.05±1.79[b]	13.94±1.16[b]
	375	70.62±0.92[b]	58.33±6.47[b]	19.67±0.18[a]	12.20±1.78[b]
	425	73.37±0.44[c]	59.00±0.74[b]	15.56±0.06[b]	11.64±0.76[b]
0	untreated	43.57±0.09[a]	44.89±1.63[a]	15.00±0.68[b]	17.53±0.61[a]
70	325	71.43±0.07[b]	62.41±0.50[c]	15.01±0.27[b]	13.55±1.72[b]
	375	72.60±0.08[c]	59.14±0.57[b]	12.20±1.78[b]	11.96±0.75[b]
	425	74.09±0.48[d]	59.42±0.96[b]	11.64±0.76[b]	11.57±0.88[b]

Different small letters; a, b, c indicate statistical difference between infrared temperature values at each same voltage gradient at α=0.05 level

At consecutive application of ultrasound, ohmic and infrared treatment, outer surface values of L*, a*, b*, H and S of beef samples were lower than that of inner surface (Table 3.13 and Table 3.14).

Outer surface of cooked beef muscles had darker, less redness and less yellowness color values. As a general, at constant ultrasound treatment time and infrared temperature, the increase of voltage gradient did not cause a significant difference ($P>0.05$) on color values (L*, a*, b*, H and S). However, there are some exceptions; inner surface of L* values at 20 min. ultrasound treatment, at 325 and 375 °F infrared cooking; on outer surface of L* values at 10 min. ultrasound treatment, at 325 and 425 °F infrared cooking, 20 min. ultrasound treatment, at 375 °F infrared cooking; on inner surface of a* values at 10 min. ultrasound treatment, at 375 and 425 °F infrared cooking, at 20 min. ultrasound treatment, at 325 °F infrared cooking. The increase of ohmic voltage gradient caused a significant decrease with these exceptions. Lower L* and a* values are acceptable to achieve the purpose of the hybrid system. Because at ohmic cooking alone process, beef samples had homogeneous brown color but lack of crust layer (higher L* and a* values for outside surface of beef samples). Thus, cooked crust visual on beef muscle had been accomplished with this hybrid system.

On the other hand, Nikmaram et al. (2011) studied the effects of microwave, roasting and braising cooking treatments on *Longissimus dorsi*. They found L* value of raw meat as 35.54; microwave as 54.84; roasting as 53.54 and braising as 56.6. When these results compared with the hybrid system of the present study, in the hybrid system more brown color values were obtained. Hsu and Chung (1998) and Hsu and Yu (1999) asserted that consumers favor a brightly colored meat ball.

Table 3.13 Color (L*, a*, b*) values of ultrasound-ohmic-infrared cooked meat at each voltage levels at each constant ultrasound time and infrared temperature

U (min.)	I (°F)	O (V)	L* (inner)	L* (outer)	a* (inner)	a* (outer)	b* (inner)	b* (outer)
0			35.23±3.53^{a}	33.68±3.19^{a}	12.11±1.15^{a}	13.11±1.15^{a}	12.52±0.86^{a}	12.52±0.86^{a}
10	325	40	41.08±2.10^{a}	37.97±1.88^{b}	7.56±0.59^{b}	6.51±1.04^{b}	13.05±0.32^{a}	8.84±2.29^{ab}
		55	41.56±3.57^{a}	35.56±0.14^{ab}	7.34±0.39^{b}	6.22±0.21^{b}	12.83±1.17^{a}	7.82±1.23^{b}
		70	40.77±3.74^{a}	31.81±0.76^{ab}	6.67±0.09^{b}	4.93±0.48^{b}	12.61±1.78^{a}	6.36±1.57^{b}
	375	40	43.18±3.09^{a}	33.65±1.06^{a}	7.42±0.21^{b}	6.29±0.45^{b}	12.44±0.38^{a}	8.23±1.75^{b}
		55	39.48±4.08^{a}	27.60±2.14^{a}	6.43±0.04^{bc}	6.03±0.53^{b}	12.38±1.96^{a}	7.72±0.15^{b}
		70	37.80±3.70^{a}	25.60±5.04^{a}	4.88±0.11^{c}	5.58±0.56^{b}	12.30±0.15^{a}	7.67±1.17^{b}
	425	40	39.27±2.17^{a}	29.95±2.47^{ab}	7.03±0.21^{b}	6.01±0.60^{b}	11.76±0.39^{a}	8.03±1.79^{b}
		55	40.41±3.06^{a}	28.87±0.41^{ab}	5.56±0.36^{bc}	5.69±0.82^{b}	11.39±0.01^{a}	7.42±0.24^{b}
		70	40.03±5.21^{a}	25.95±2.67^{b}	4.20±0.73^{c}	5.26±0.62^{b}	10.74±0.96^{a}	7.08±0.80^{b}
0			35.23±3.53^{a}	33.68±3.19^{a}	12.11±1.15^{a}	13.11±1.15^{a}	12.52±0.86^{a}	12.52±0.86^{a}
20	325	40	41.87±1.32^{c}	34.28±3.29^{a}	6.69±0.04^{b}	5.90±0.42^{b}	12.91±0.09^{a}	8.72±0.70^{b}
		55	33.17±0.19^{ab}	29.05±2.43^{a}	5.18±0.24^{bc}	5.37±0.63^{b}	12.39±0.67^{a}	7.71±1.55^{b}
		70	39.53±1.21^{bc}	28.33±2.20^{a}	4.55±0.42^{c}	5.19±0.79^{b}	12.17±0.42^{a}	6.95±0.35^{b}
	375	40	42.73±1.51^{b}	30.45±3.54^{ab}	5.51±0.18^{b}	5.65±0.32^{b}	12.38±0.19^{a}	8.31±0.09^{b}
		55	40.08±2.57^{ab}	27.49±1.44^{ab}	5.11±0.05^{b}	5.21±0.70^{b}	12.06±1.23^{a}	8.05±0.49^{b}
		70	41.83±1.10^{ab}	25.35±1.96^{b}	4.99±0.41^{b}	5.09±1.31^{b}	11.63±0.21^{a}	7.35±0.38^{b}
	425	40	38.01±3.77^{a}	27.53±1.51^{ab}	4.97±0.01^{b}	5.42±0.33^{b}	11.84±0.56^{a}	7.93±0.24^{b}
		55	40.22±2.22^{a}	26.03±3.95^{b}	4.21±0.02^{b}	4.69±0.33^{b}	11.32±0.21^{a}	6.94±0.69^{b}
		70	42.66±1.73^{a}	25.63±0.66^{b}	4.10±0.31^{b}	4.38±1.32^{b}	10.53±1.44^{a}	6.55±1.68^{b}
0			35.23±3.53^{a}	33.68±3.19^{a}	12.11±1.15^{a}	13.11±1.15^{a}	12.52±0.86^{a}	12.52±0.86^{a}
30	325	40	38.56±1.45^{ab}	30.09±3.04^{a}	5.16±0.35^{b}	5.84±1.14^{b}	12.87±0.82^{a}	8.79±1.61^{b}
		55	35.61±1.32^{a}	27.64±3.93^{a}	4.93±0.77^{b}	5.42±0.69^{b}	12.49±0.97^{a}	8.09±0.77^{b}
		70	42.23±0.21^{b}	26.20±2.14^{a}	4.78±0.01^{b}	5.16±0.60^{b}	11.44±0.73^{a}	7.84±0.52^{b}
	375	40	40.18±0.26^{ab}	29.64±1.32^{ab}	5.06±0.09^{b}	4.94±0.21^{b}	12.96±1.13^{a}	8.64±0.29^{b}
		55	40.14±0.57^{ab}	26.61±0.08^{b}	4.64±0.50^{b}	4.64±0.60^{b}	11.80±0.01^{a}	7.98±0.65^{b}
		70	42.21±0.89^{b}	25.09±0.36^{b}	4.03±0.48^{b}	4.38±0.52^{b}	11.36±0.79^{a}	7.54±0.42^{b}
	425	40	42.20±1.52^{a}	27.28±4.08^{ab}	4.74±0.43^{b}	4.81±1.03^{b}	11.80±1.10^{a}	7.66±2.30^{b}
		55	40.70±3.13^{a}	24.93±3.93^{b}	4.44±0.18^{b}	4.22±0.25^{b}	11.29±0.42^{a}	6.88±1.93^{b}
		70	40.57±1.49^{a}	22.07±0.24^{b}	3.89±0.26^{b}	4.05±1.47^{b}	10.25±0.98^{a}	6.51±1.52^{b}

Different small letters; a, b, c indicate statistical difference between voltage gradient values of ultrasound-ohmic-infrared cooking at each constant ultrasound time and infrared temperature (α=0.05 level). Abbreviations: U: Ultrasound; °F: Fahrenheit Degree; I: Infrared; O: Ohmic; V: Volt

Table 3.14 Color (Hue and Chroma) values of ultrasound-ohmic-infrared cooked meat at each voltage levels at each constant ultrasound time and infrared temperature

Ultrasound (min.)	Infrared (°F)	Ohmic (Volt)	Hue (inner)	Hue (outer)	Chroma (inner)	Chroma (outer)
Raw			45.98±0.77[a]	43.70±0.56[a]	17.41±1.42[a]	18.12±1.43[a]
10	325	40	59.90±2.58[b]	53.31±2.76[b]	15.08±0.01[a]	10.98±2.46[b]
		55	60.12±3.59[b]	51.27±5.35[b]	14.79±0.82[a]	10.01±0.82[b]
		70	61.95±3.01[b]	51.66±9.57[b]	14.27±1.62[a]	8.10±0.93[b]
	375	40	59.17±1.49[b]	52.29±3.94[b]	14.48±0.21[ab]	10.37±1.66[b]
		55	62.31±3.90[b]	52.04±1.91[b]	13.96±1.72[b]	9.79±0.45[b]
		70	68.36±0.20[c]	53.86±1.42[b]	13.23±0.18[b]	9.48±1.28[b]
	425	40	59.11±1.61[b]	52.87±3.41[b]	13.70±0.23[b]	10.03±1.80[b]
		55	63.99±1.52[bc]	52.63±3.09[b]	12.67±0.14[b]	9.35±0.68[b]
		70	68.50±5.14[c]	53.22±0.12[b]	11.55±0.62[b]	8.82±1.01[b]
Raw			45.98±0.77[a]	43.70±0.56[a]	17.41±1.42[a]	18.12±1.43[a]
20	325	40	62.60±0.02[b]	55.90±0.24[b]	14.54±0.10[b]	10.52±0.82[b]
		55	67.27±2.06[c]	54.94±2.27[b]	13.43±0.53[b]	9.39±1.63[b]
		70	69.47±2.40[c]	53.36±2.80[b]	12.99±0.24[b]	8.67±0.75[b]
	375	40	66.01±0.37[b]	55.80±1.21[b]	13.55±0.25[b]	10.04±0.26[b]
		55	66.93±2.33[b]	57.08±5.14[b]	13.10±1.11[b]	9.60±0.03[b]
		70	66.79±1.32[b]	55.62±5.56[b]	12.65±0.35[b]	8.96±1.06[b]
	425	40	67.21±0.91[b]	55.64±2.48[b]	12.84±0.52[b]	9.60±0.01[b]
		55	69.59±0.48[b]	55.91±0.73[b]	12.07±0.18[b]	8.37±0.76[b]
		70	68.50±4.15[b]	56.39±1.27[b]	11.31±1.22[b]	7.88±2.13[b]
Raw			45.98±0.77[a]	43.70±0.56[a]	17.41±1.42[a]	18.12±1.43[a]
30	325	40	68.09±2.61[b]	56.06±9.99[b]	13.87±0.63[b]	10.63±0.70[b]
		55	68.35±4.61[b]	56.22±0.84[b]	13.44±0.62[b]	9.73±1.03[b]
		70	67.29±1.25[b]	56.69±1.35[b]	12.39±0.68[b]	9.38±0.77[b]
	375	40	68.62±1.32[b]	60.22±1.90[b]	13.91±1.08[b]	9.95±0.15[b]
		55	68.54±2.16[b]	59.87±1.23[b]	12.68±0.17[b]	9.23±0.86[b]
		70	70.50±0.89[b]	61.27±0.36[b]	12.05±0.90[b]	8.72±0.62[b]
	425	40	68.11±0.01[b]	57.55±2.31[b]	12.71±1.18[b]	9.04±2.50[b]
		55	68.51±1.54[b]	57.64±8.84[b]	12.13±0.32[b]	8.11±1.50[b]
		70	69.09±3.15[b]	58.57±3.42[b]	10.97±0.82[b]	7.67±2.07[b]

Different small letters; a, b, c indicate statistical difference between voltage gradient values of ultrasound-ohmic-infrared cooking at each constant ultrasound time and infrared temperature (α=0.05 level)

3.4 Texture

Texture profile of beef muscle (hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience) was followed during the processing of ohmic, infrared, ultrasound-ohmic, ohmic-infrared, ultrasound-ohmic-infrared cooking. The results and the statistical analyses were seen in the Figures 3.12- 3.35.

At ohmic cooking alone process, the textural behaviours of the ohmic cooked beef samples were significantly different from ($P<0.05$) raw material. Moreover, there was a significant difference ($P<0.05$) in all texture profile values by increasing voltage gradient. Lyng and Mckenna (2013) indicated that higher ohmic voltage densities produced faster heating rates. Faster heating rate caused structural changes in meat product; such as denaturation of proteins, destruction of cell membranes and shrinkage of myofibrillar structure. In this study, hardness values of ohmic cooked beef were higher with application of 40 V than application of 55 and 70 V (Figure 3.12). The increase in hardness could be explained by coagulation of protein (myosin) in meat caused to squeeze of water around the groups of myosin and the protein could coagulate even more, cells could form into more solid groups, so the meat became firmer and larger pockets of liquid made it juicer. As the increasing of voltage gradient, the collagen could be denaturated in the connective tissue and put more pressure on the water. As a result, the meat could shrink and release much of its juice and became tougher. By increasing voltage gradient more, hardness value decreased. This could be due to collagen changed into soft gelatin and meat released it tight texture (Huidobro et al., 2005; Uzun, 2010). Genççelep (2008) indicated that the change in the hardness has been recommended as a good indicator to explain the changes in meat texture.

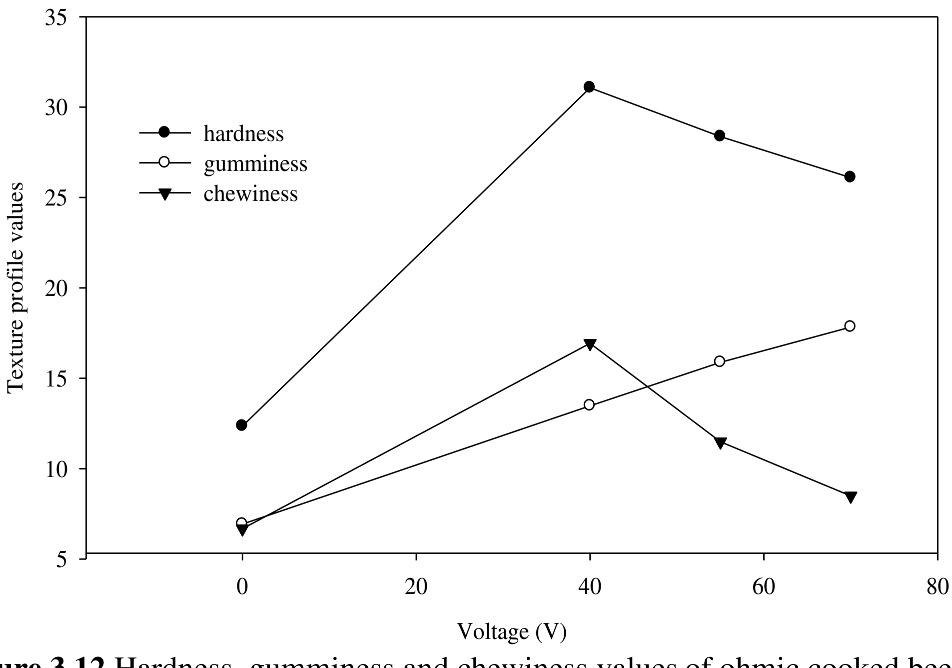

Figure 3.12 Hardness, gumminess and chewiness values of ohmic cooked beef

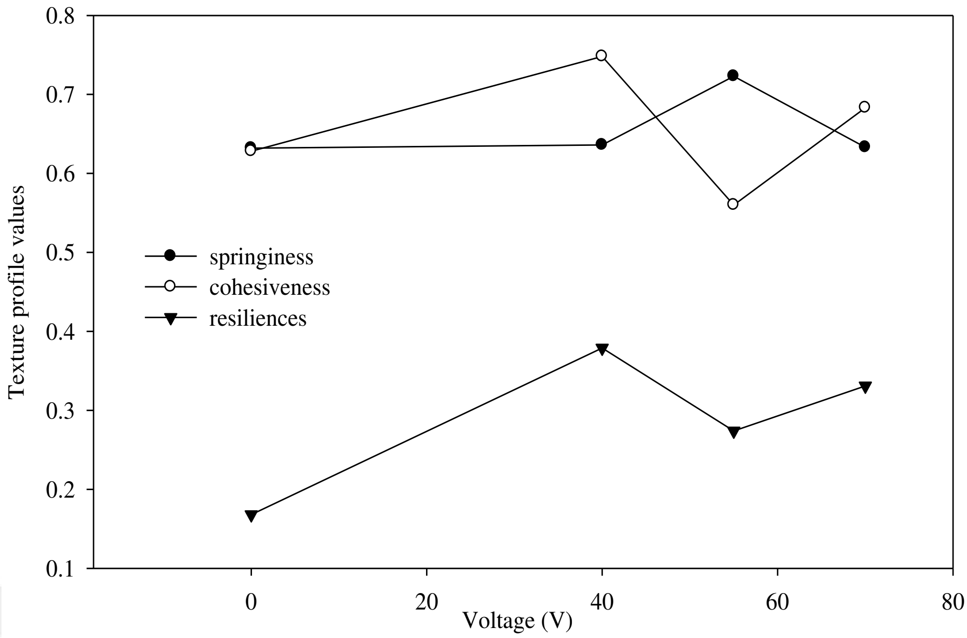

Figure 3.13 Springiness, cohesiveness and resiliences values of ohmic cooked beef

Chewiness is the force required to bite through the chewed sample. Increase in chewiness values indicated that meat became tougher during the processing (Szczesniak, 2002). Chewiness value of ohmic cooked beef samples firstly increased then decreased as in the hardness value. Adhesiveness and gumminess values increased significantly ($P<0.05$) by the increase of voltage gradient. Springiness values were varied between 0.632 and 0.723 while cohesiveness ranged between 0.628 and 0.748 during the ohmic processing (Figure 3.13). İçier et al. (2010) studied ohmic thawing (-18 to +10 °C) on textural properties of beef cuts (2.5 × 2.5 × 5 cm) by applying different voltage gradients (10, 20, 30 V/cm; 828, 703 and 586 s respectively). They found that voltage gradient had a significant effect on hardness, gumminess, chewiness and springiness values of thawed beef cuts and 20 V/cm voltage gradient caused harder, chewy and gummy thawed meat cuts than other voltage gradients. Zell et. al. (2009) indicated that one of the major advantages of ohmic heating is the improved juiciness compared to other heating technologies.

At infrared cooking alone, textural attributes of cooked beef samples were significantly different ($P<0.05$) from raw samples (Figure 3.14 and Figure 3.15). Moreover, texture profile values of infrared cooked samples were higher than ohmically cooked samples. This could be due to when a meat patty is heated by infrared radiation, a high surface temperature is established within a minute and further heat transmission into the meat releases more water and this migrates outwards which caused higher texture profile values (Sheridan and Shilton, 2002). Hardness value increased significantly ($P<0.05$) by increasing infrared temperature. Chewiness and gumminess value increased significantly ($P<0.05$) by increasing infrared temperature 325 to 375 °F but decreased insignificantly by increasing infrared temperature 375 to 425 °F. Increase in infrared temperature did not cause a significant effect ($P>0.05$) on adhesiveness and gumminess value. Springiness, cohesiveness and resiliences values showed similar trend by increasing infrared temperature. There were not many studies available in the literature about the effect of infrared cooking method on textural attributes of beef meat. Khan and Vandermey (1985) prepared ground beef patties by infrared broiling in a conveyorized broiler. They indicated that ground beef patties broiled by tube broiler did not have any adverse effects on the texture, especially juiciness quality as compared to conventional gas broiling method.

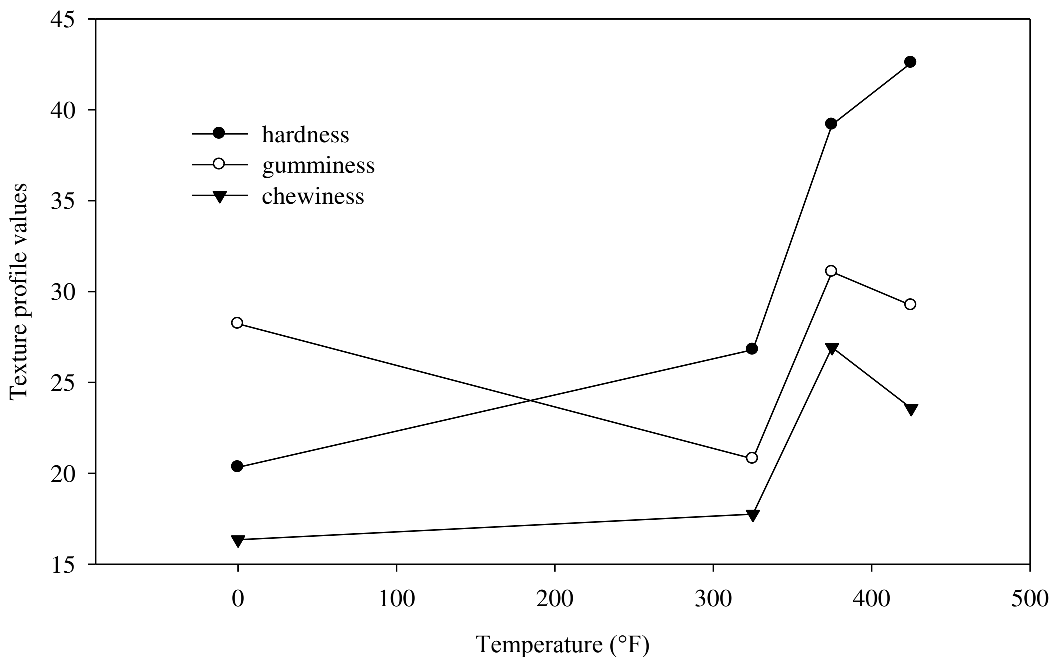

Figure 3.14 Hardness, gumminess, chewiness values of infrared cooked beef

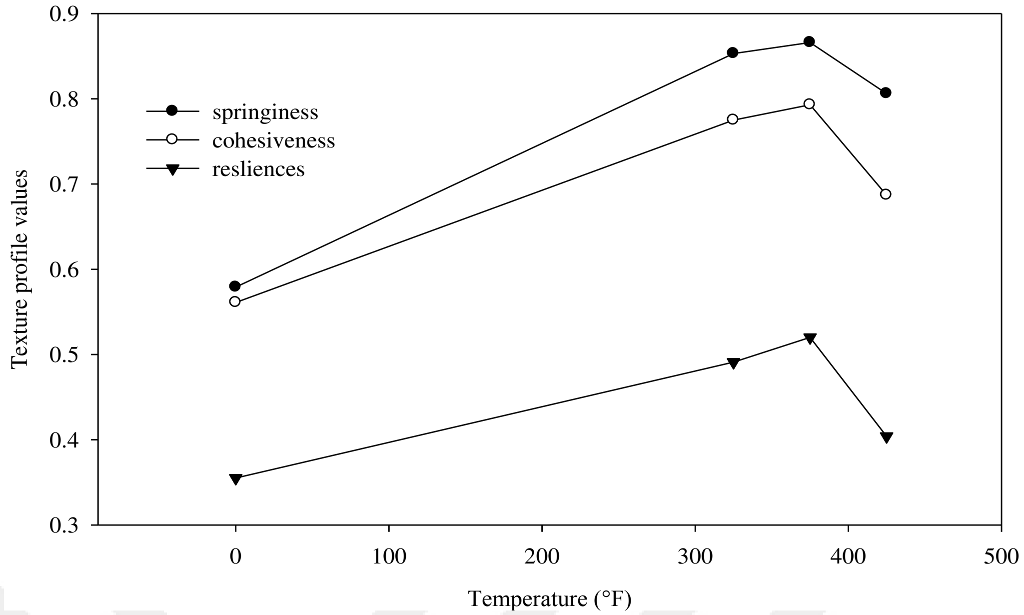

Figure 3.15 Springiness, cohesiveness, resiliences values of infrared cooked beef

At consecutive application of ultrasound treatment with ohmic cooking, according to two way ANOVA results, the interaction of ultrasound and ohmic treatment cause a significant effect on hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resiliences of beef muscle (P<0.05). This could be due to ultrasound can assist restructuring of meat proteins and tenderising of meat (Vimini et al., 1983). At constant voltage gradient of 40, 55 and 70 V, the increase of ultrasound time caused a significant difference in hardness and chewiness value of ultrasound-ohmic cooked beef samples according to one way ANOVA results (Figure 3.16 and Figure 3.21). Springiness and cohesiveness manifested the same trend by ohmic-ultrasound interaction (Figure 3.18 and Figure 3.19). However, there were no significant effect (P>0.05) on adhesiveness and resilience value (Figure 3.17 and 3.22). This was in aggrement with the study of Zhou et al. (2012). They investigated the effect of low frequency and high-power ultrasound (40 kHz, 1500 W) by applying different sonicating time (10, 20, 30, 40, 50 and 60 min.) to evaluate the effects of characteristics changes of collagen on meat quality and texture properties. It was found that the ultrasound treatment had significant effects (P<0.05) on hardness, springiness, cohesiveness, gumminess, and chewiness, but not significant effects (P>0.05) on adhesiveness and resilience.

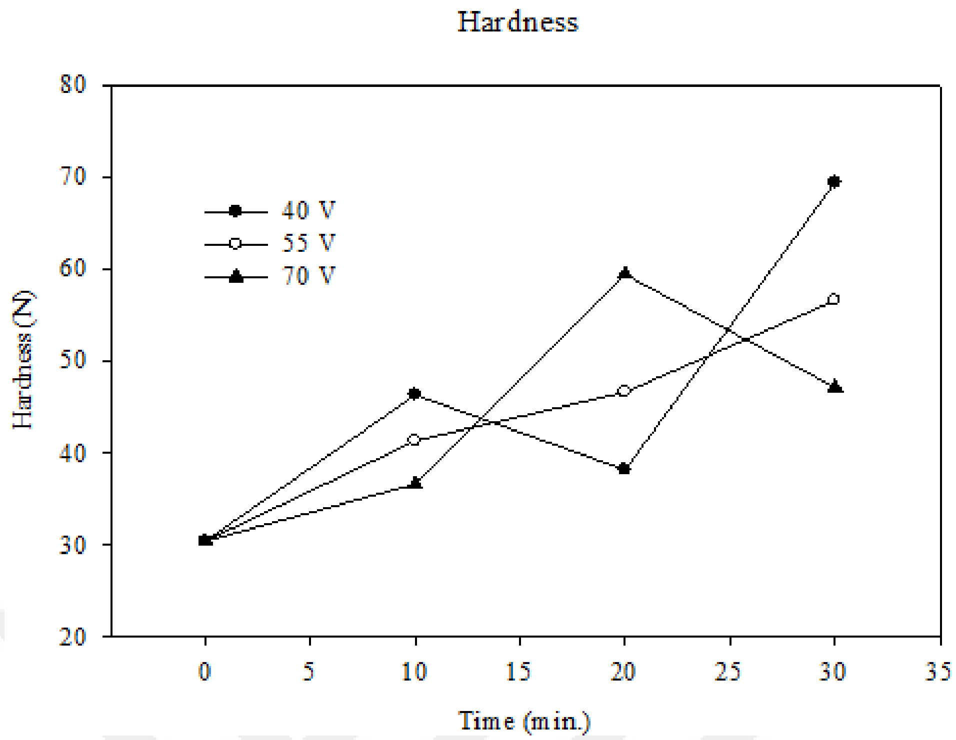

Figure 3.16 Hardness values of ultrasound-ohmic cooked beef at constant ohmic voltage

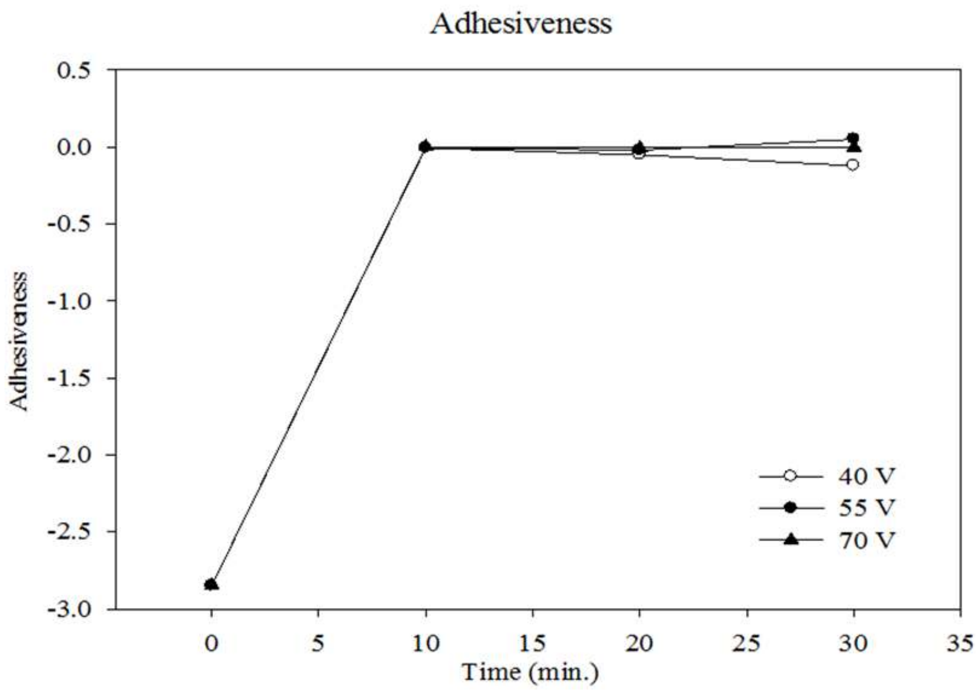

Figure 3.17 Adhesiveness values of ultrasound-ohmic cooked beef at constant ohmic voltage

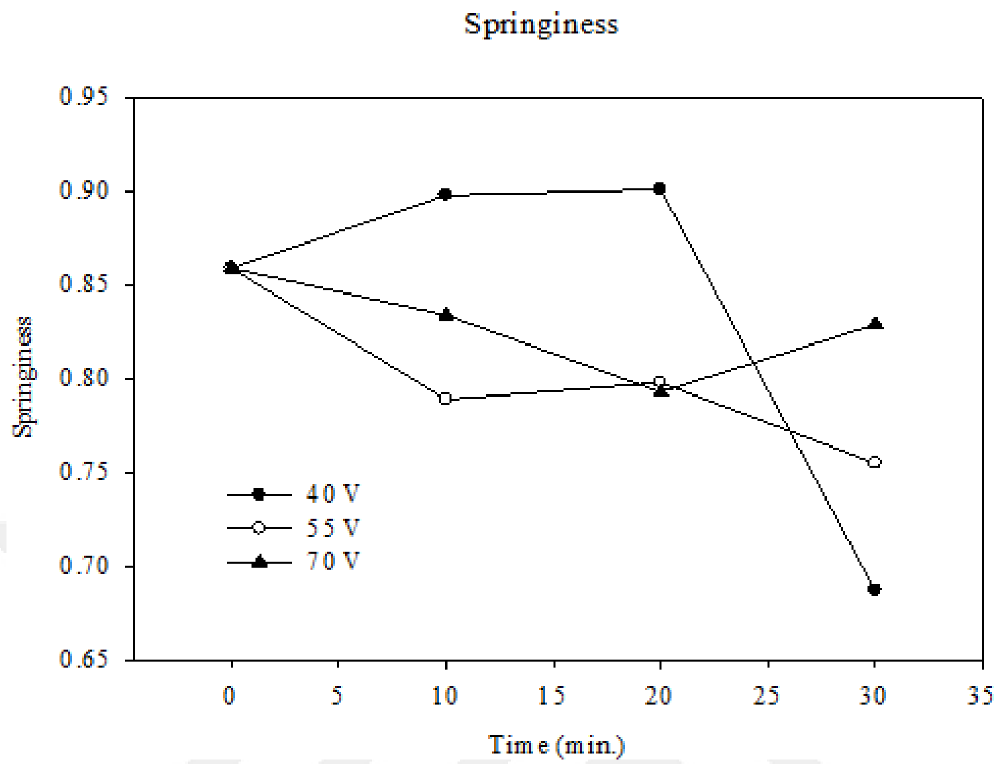

Figure 3.18 Springiness values of ultrasound-ohmic cooked beef at constant ohmic voltage

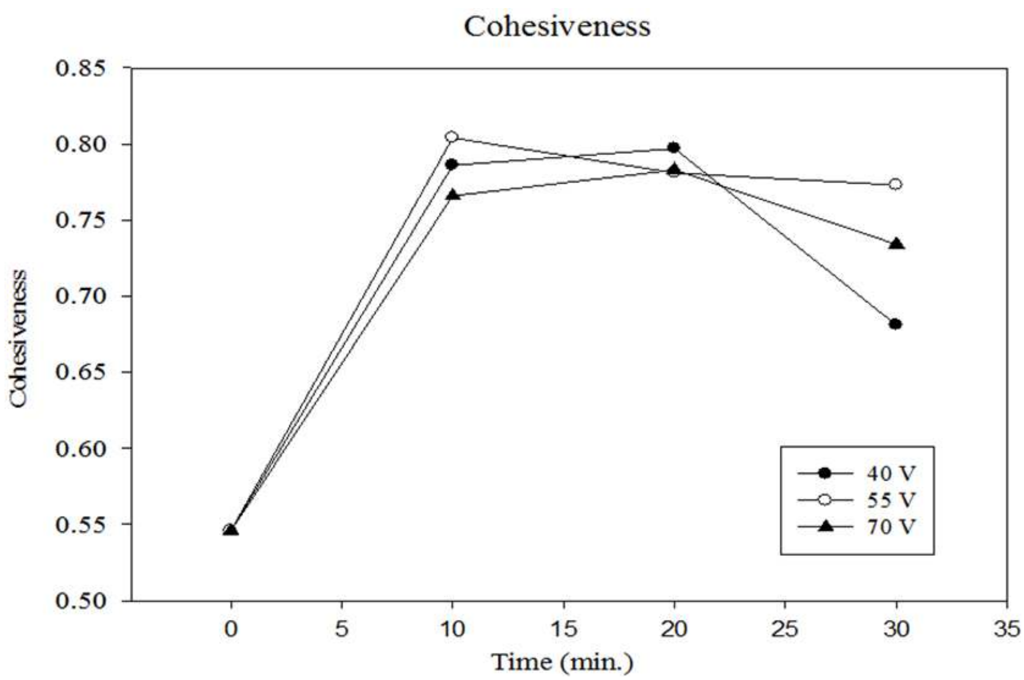

Figure 3.19 Cohesiveness values of ultrasound-ohmic cooked beef at constant ohmic voltage

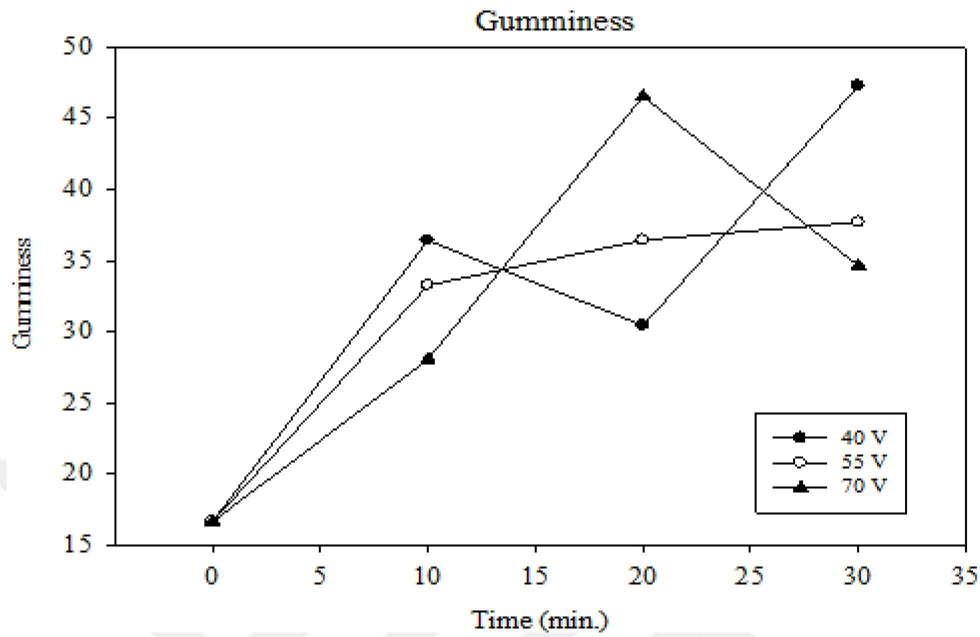

Figure 3.20 Gumminess values of ultrasound-ohmic cooked beef at constant ohmic voltage

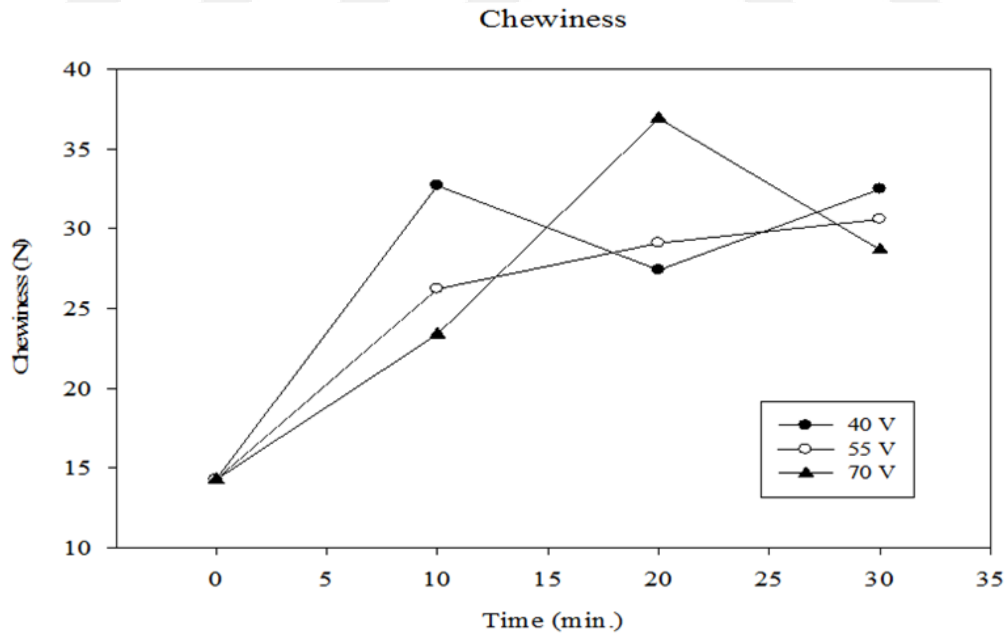

Figure 3.21 Chewiness values of ultrasound-ohmic cooked beef at constant ohmic voltage

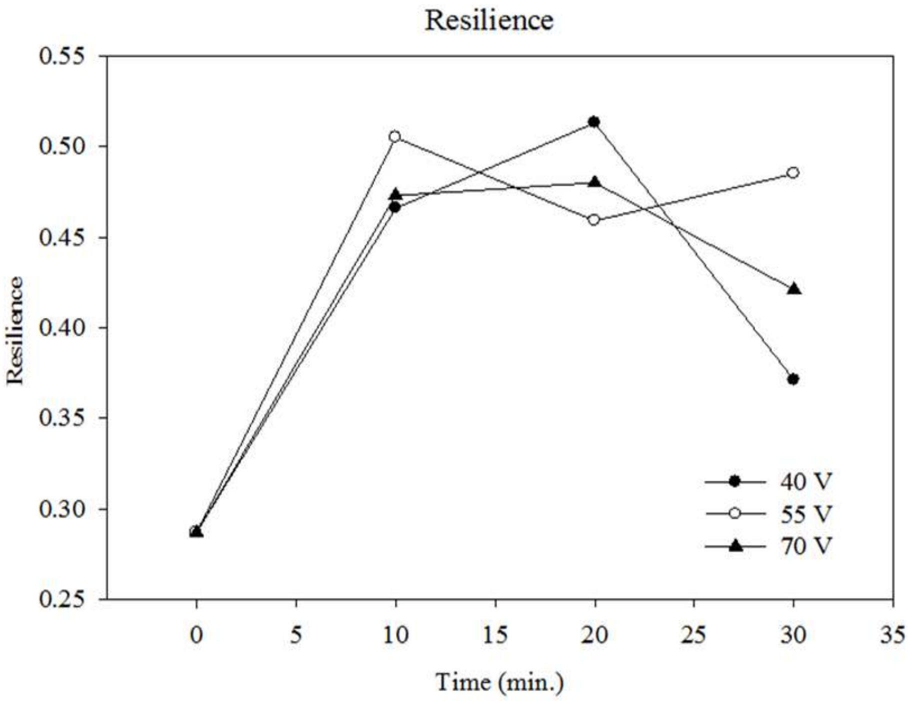

Figure 3.22 Resilience values of ultrasound-ohmic cooked beef at constant ohmic voltage

At consecutive application of ohmic and infrared cooking, all texture profile values of cooked beef samples were significantly higher than raw beef samples. According to two way ANOVA results, ohmic cooking followed by infrared treatment cause a significant effect on hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resiliences of beef muscle ($P<0.05$) as it was in the ultrasound-ohmic interaction. According to one way ANOVA results, at constant ohmic voltage level, the increase of infrared temperature caused a significant difference on hardness and chewiness value of beef muscle. Hardness and chewiness values firstly increased then decreased by increasing infrared temperature (Figure 3.23 and Figure 3.27). The increase of infrared temperature caused no difference in adhesiveness, springiness and resiliences value. Gumminess value increased significantly by increasing infrared temperature at 40 V, however at 55 and 70 V, it increased significantly only at 425 °F infrared temperature (Figure 3.28). This could be due to more heat denaturation and more structural changes caused by increased temperature. Yıldız-Turp et al. (2016) studied the combination of ohmic (15.26 V, 92 s) and infrared cooking of meatball samples with different heat fluxes, distances and durations and investigated the effect of infrared cooking on texture values of ohmicaly pre-cooked beef samples. They observed that the texture of the samples was also improved with these parameters. However, most of the interaction effects of the combinations of parameters on textural characteristics were found as nonsignificant. Khan and Vandermey (1985) compared the treatments of infrared and gas broiling of beef samples by means of texture, juiciness and overall acceptability and indicated that there were no significant difference between two methods.

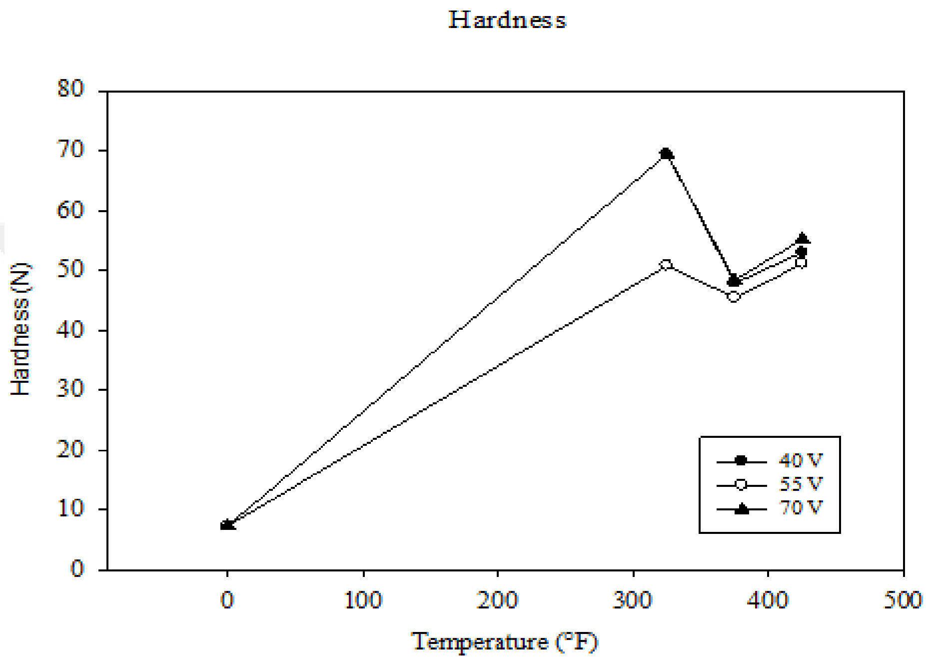

Figure 3.23 Hardness values of ohmic-infrared cooked beef at constant ohmic voltage

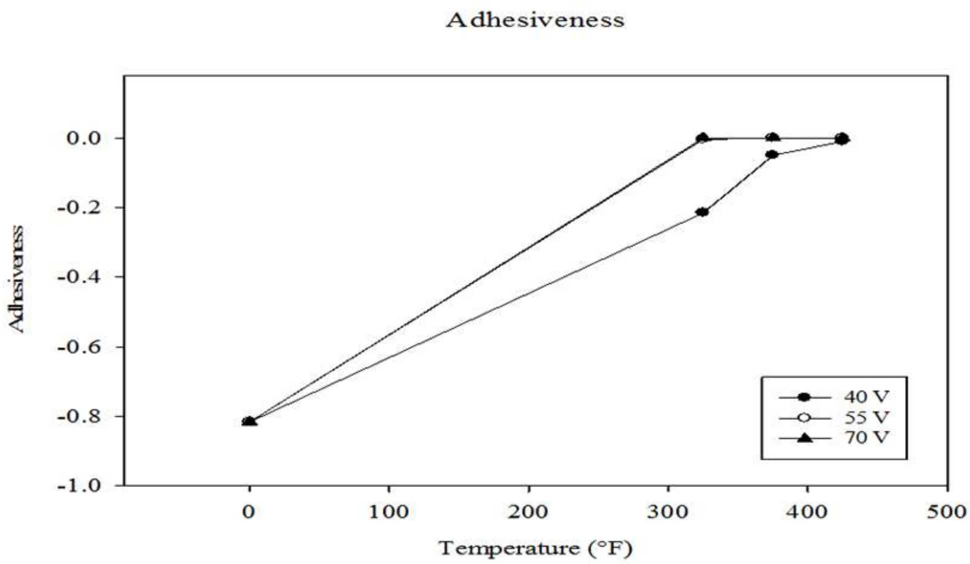

Figure 3.24 Adhesiveness values of ohmic-infrared cooked beef at constant ohmic voltage

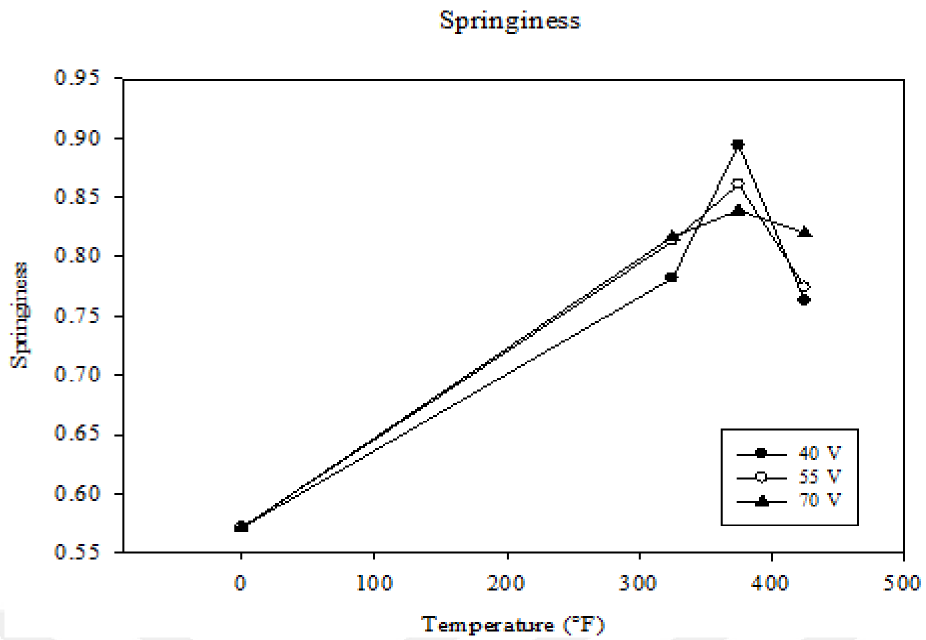

Figure 3.25 Springiness values of ohmic-infrared cooked beef at constant ohmic voltage

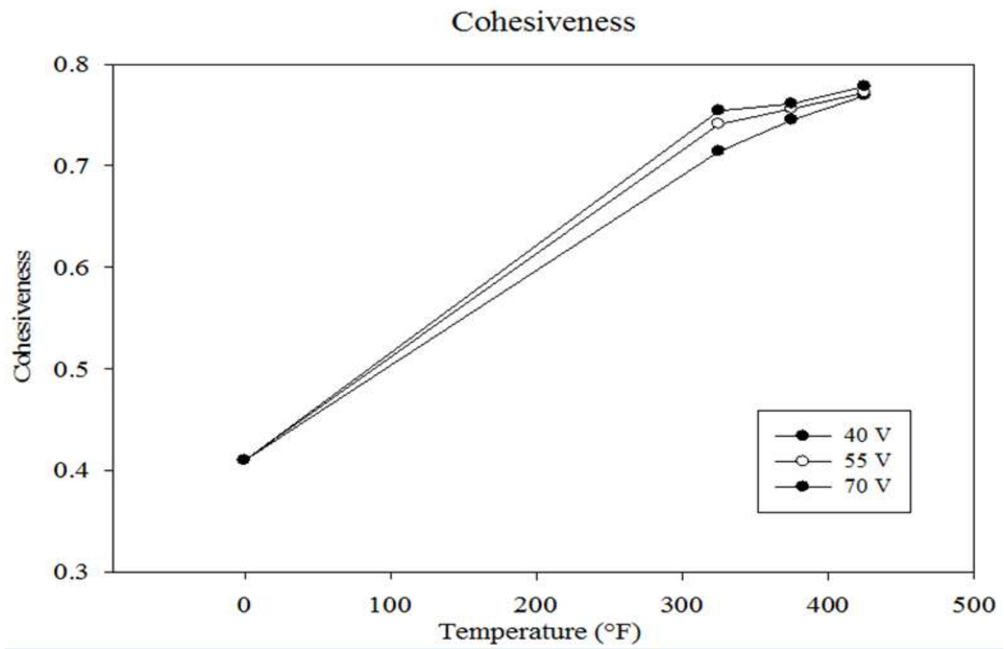

Figure 3.26 Cohesiveness values of ohmic-infrared cooked beef at constant ohmic voltage

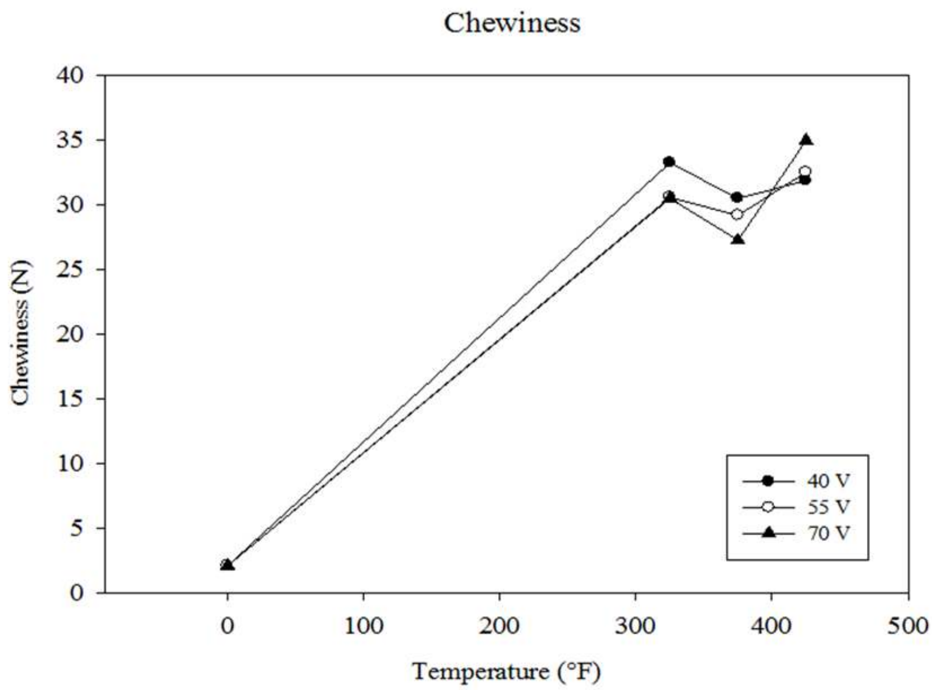

Figure 3.27 Chewiness values of ohmic-infrared cooked beef at constant ohmic voltage

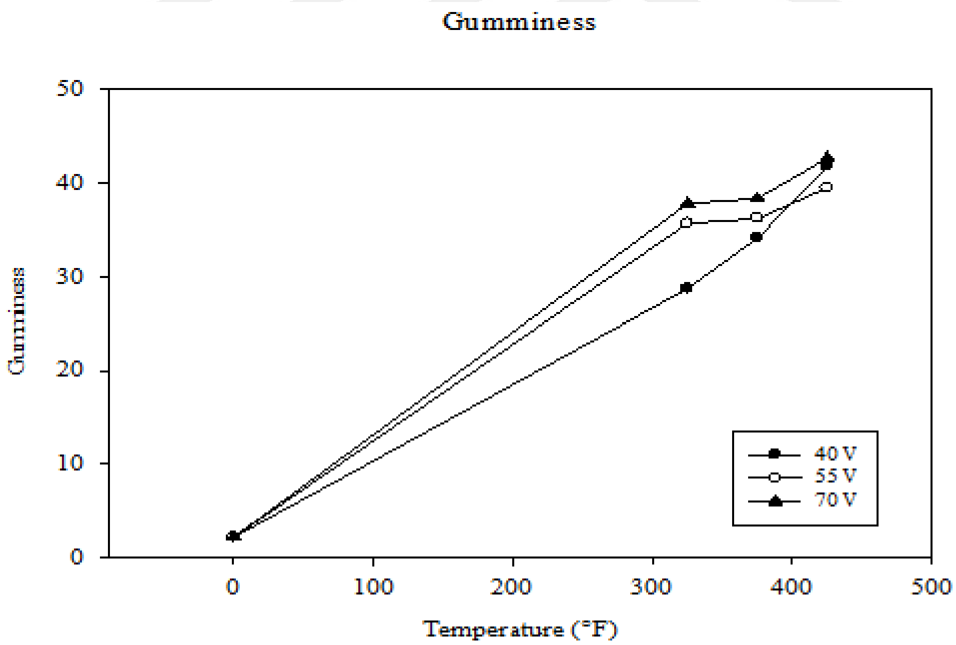

Figure 3.28 Gumminess values of ohmic-infrared cooked beef at constant ohmic voltage

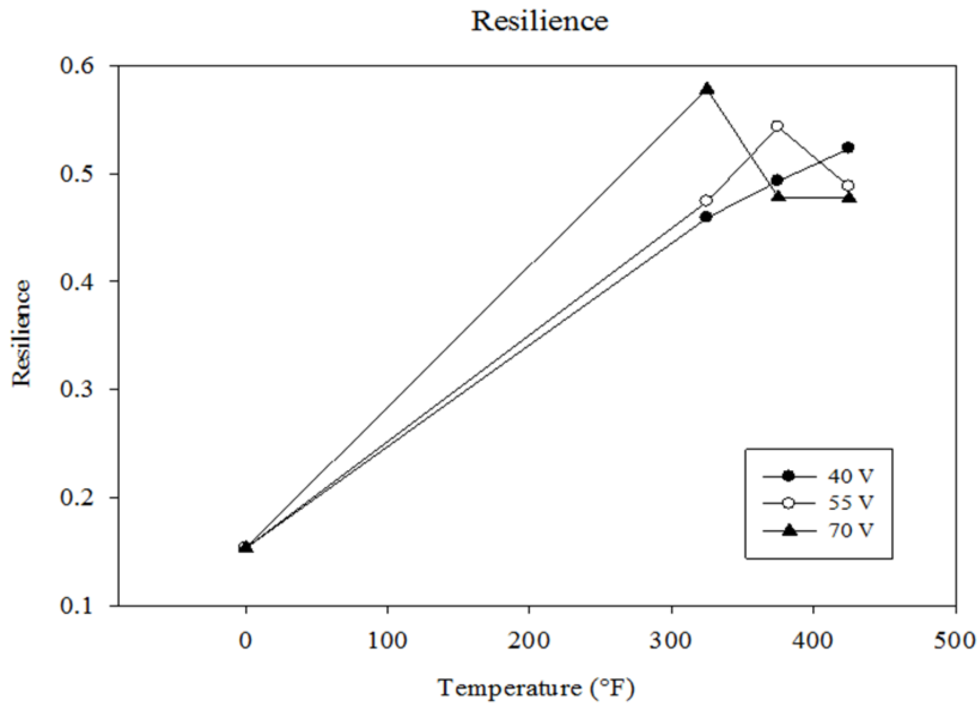

Figure 3.29 Resilience values of ohmic-infrared cooked beef at constant ohmic voltage

At consecutive application of ultrasound, ohmic and infrared treatment, at constant ultrasound time and infrared temperature, voltage increment had a significant effect ($P<0.05$) on hardness, chewiness and gumminess values of some of the samples (Figure 3.30, Figure 3.33 and Figure 3.35). On the other hand springiness, cohesiveness and resiliences values of many of samples were not affected significantly ($P>0.05$) by voltage gradient according to one way ANOVA results (Figure 3.31, Figure 3.32 and Figure 3.34). The highest hardness and chewiness values were generally obtained at 70 V values of ohmically cooked samples. These were cooked at 10 min. ultrasound+ 70 V ohmic+ 325 °F infrared, 20 min. ultrasound +70 V ohmic +425 °F infrared and 30 min.+70 V+ 375 °F. This could be due to high heating rates, temperatures and greatest power absorption reached at 70 V ohmic interaction which caused harder, chewy and gummy beef samples than those at 40 and 55 V treated samples.

In the literature, generally there are studies about comparison betwen textural attributes of ohmic and other cooking treatments such as convection, steam cooking etc (Piette et al., 2004). There is no studies about the combination of ultrasound-ohmic, ohmic-infrared or ultrasound-ohmic-infrared applications. There are some studies about the investigation of the quality of hamburger patties by combined ohmic and conventional cooking (Özkan et al., 2004; Lyng et al., 2010). Özkan et al. (2004) reported that the meat cooked by the combined cooking was slightly less chewy and the application of ohmic heating to hamburger patties does not affect the texture of the meat. Lyng et al. (2010) indicated a similar level of tenderness amongst the combined ohmic/convection and convection alone.

Actually, combination of ohmic cooking and infrared cooking with other alternative cooking methods is considered to be more efficient over ohmic cooking alone or infrared cooking alone since it gives a synergistic effect. Three way ANOVA results showed that ultrasound, ohmic and infrared interaction namely hybrid cooking caused a significant effect ($P<0.05$) on hardness, gumminess and resiliences of beef muscle, however, on springiness, cohesiveness and chewiness values it did not cause a significant effect ($P>0.05$).

In the hybrid system, ultrasound treatment had a significant effect on gumminess and chewiness; ohmic treatment had a significant effect on springiness and cohesiveness; infrared treatment had a significant effect on springiness, gumminess and resiliences, respectively. Moreover, in this hybrid system, ultrasound-ohmic interaction had a significant effect on gumminess and resiliences; ultrasound-infrared interaction had a significant effect on hardness, cohesiveness, gumminess, chewiness, resiliences; ohmic-infrared interaction had a significant effect on gumminess.

The Figures 3.30 – 3.35 at below, samples are indicated by three numbers; first represents the ultrasound time in minute, second represents the ohmic voltage level and third represents the infrared temperature value.

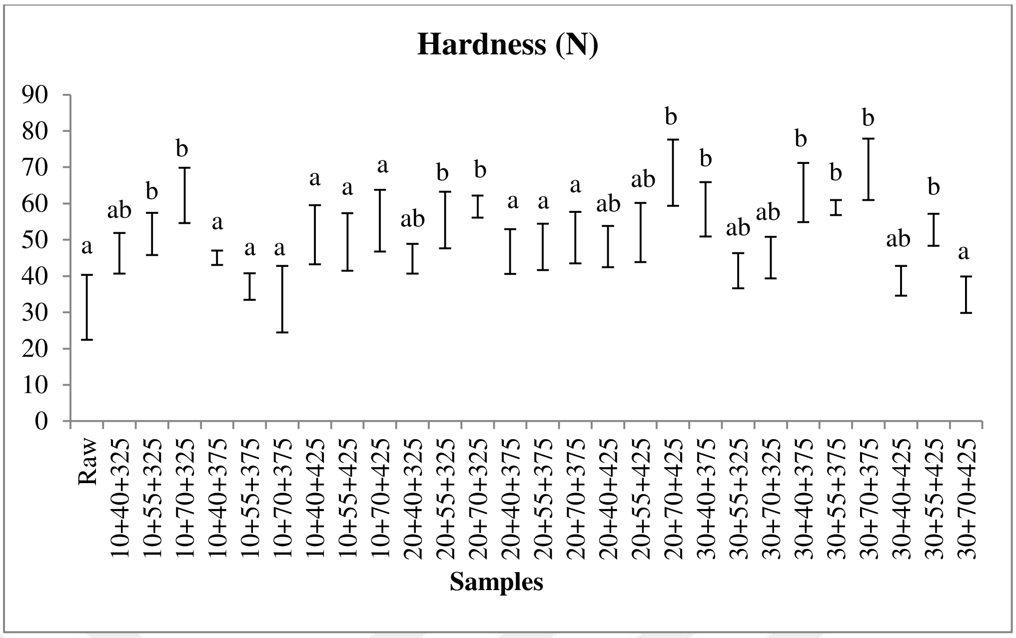

Figure 3.30 Hardness values of hybrid cooking (ultrasound+ohmic+infrared)

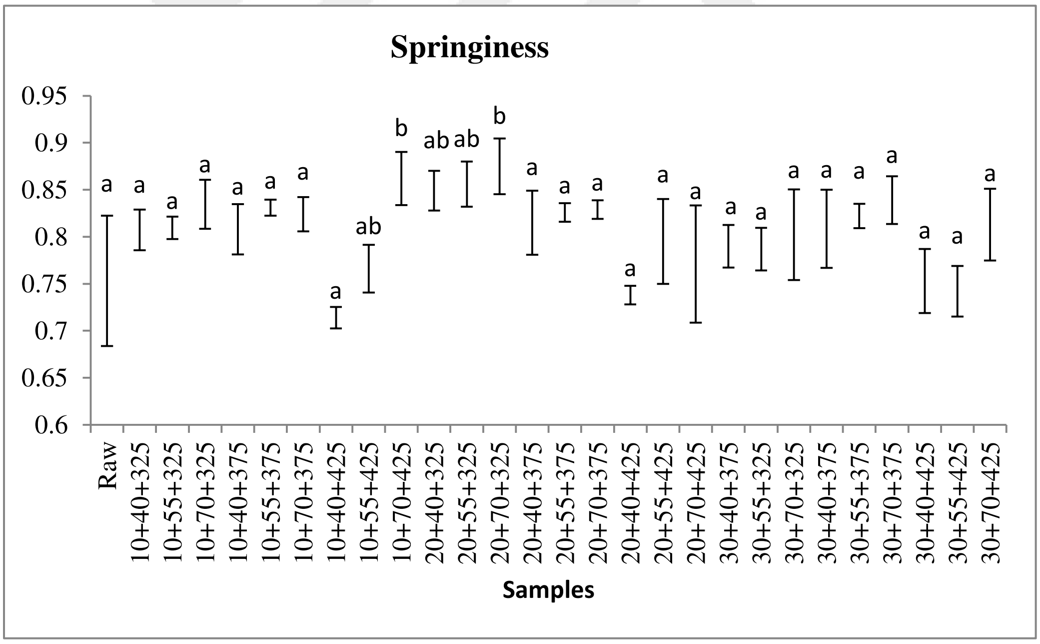

Figure 3.31 Springiness values of hybrid cooking (ultrasound+ohmic+infrared)

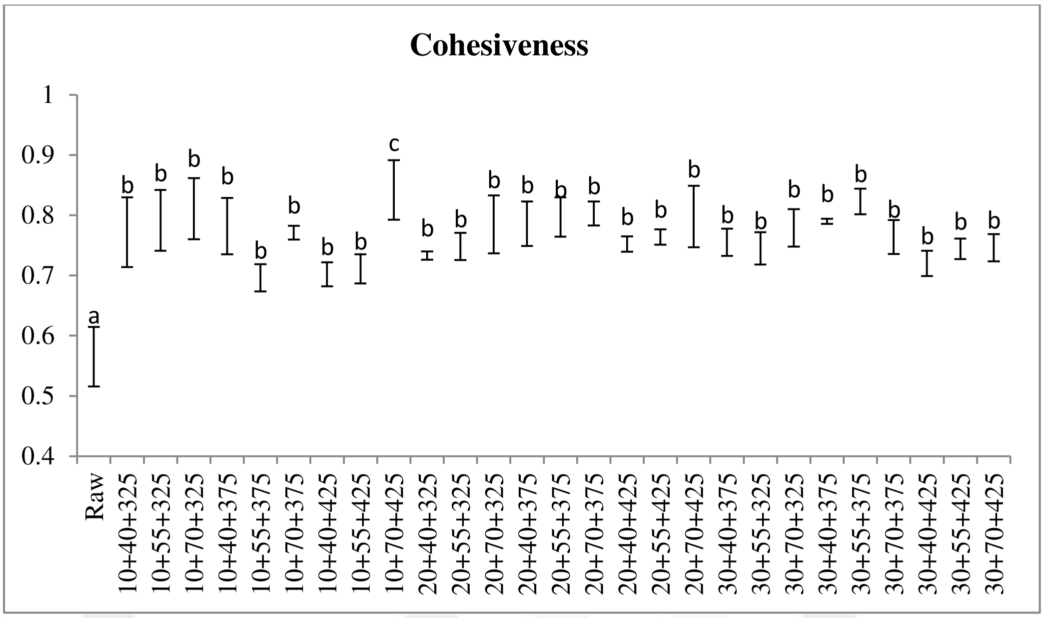

Figure 3.32 Cohesiveness values of hybrid cooking (ultrasound+ohmic+infrared)

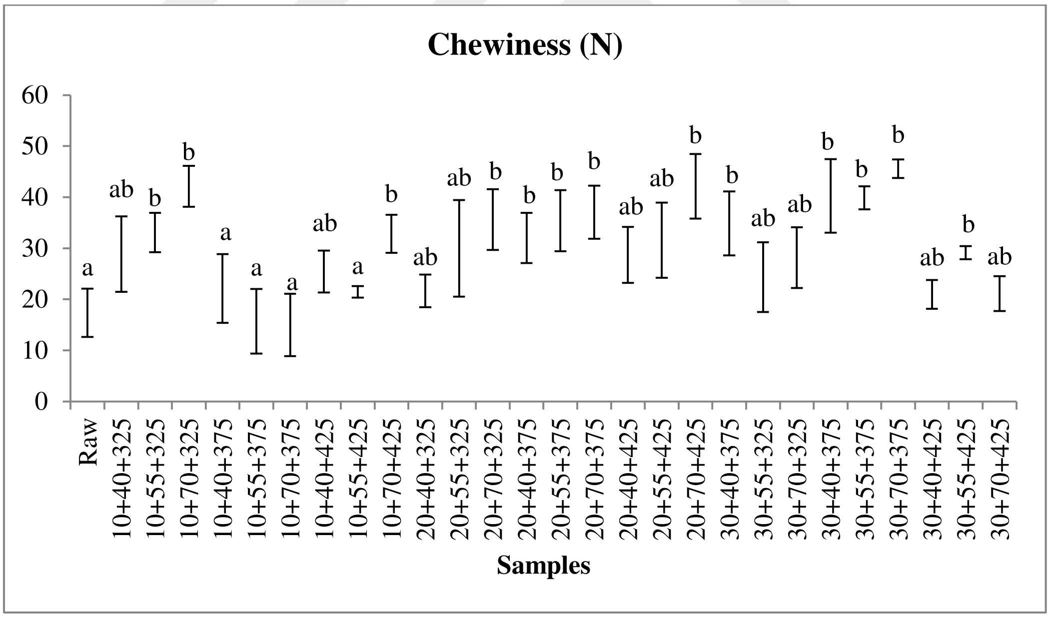

Figure 3.33 Chewiness values of hybrid cooking (ultrasound+ohmic+infrared)

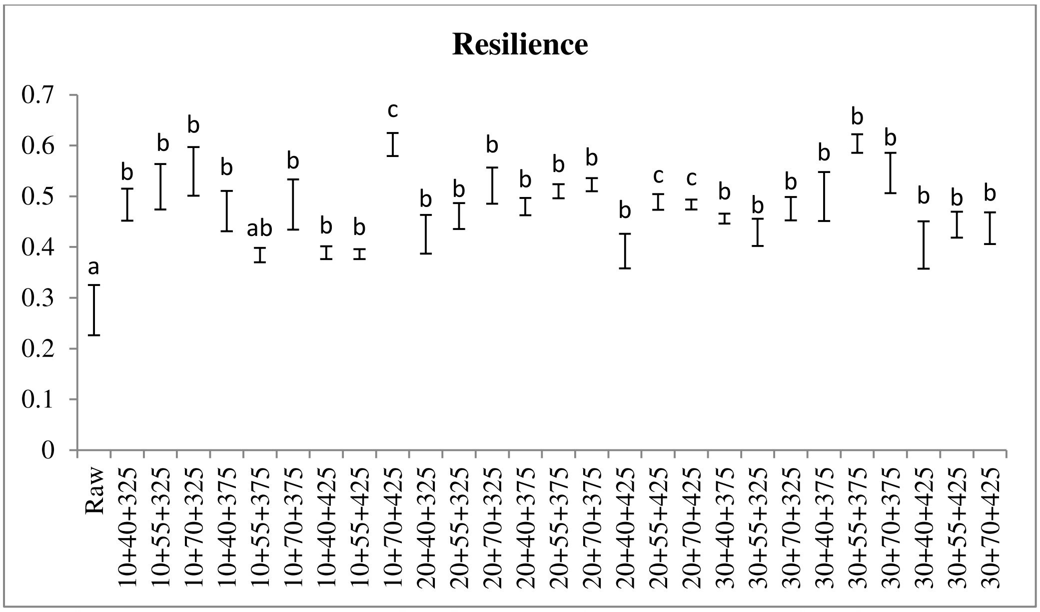

Figure 3.34 Resilience values of hybrid cooking (ultrasound+ohmic+infrared)

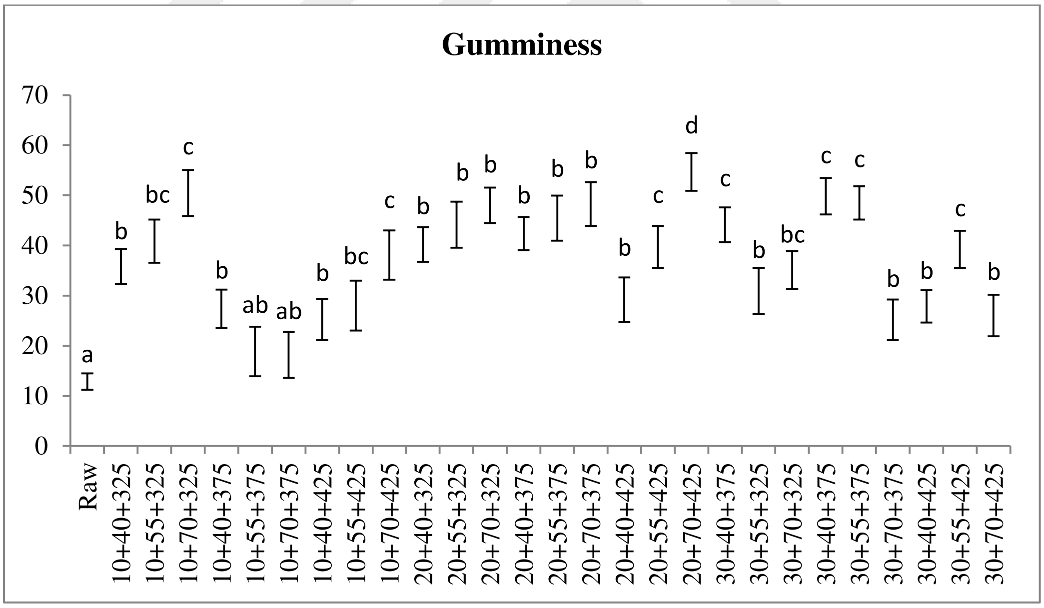

Figure 3.35 Gumminess values of hybrid cooking (ultrasound+ohmic+infrared)

3.5 Thiobarbituricacid reactive substances (TBARS)

Lipid oxidation is one of the major causes of deterioration in meat quality. The oxidation of membrane lipids can be assessed by measurement of plasma malondialdehyde (MDA), a breakdown product of lipid peroxides (Autrup et al., 1999). Lipid oxidation values of ohmic, infrared, ultrasound-ohmic, ohmic-infrared, ultrasound-ohmic-infrared cooked samples which expressed as TBARS (mg MDA/kg muscle) were followed during the process (Tables 3.15 - 3.18; Figure 3.36).

In ohmic cooking process alone, increasing voltage value increased TBARS value significantly ($P<0.05$) (Table 3.15). In ohmic processing, the increase of temperature could be due to agitation of molecules due to movement of charges within the material by flowing of electric current through a conductor (Ramaswamy et al., 2014). Min et al. (2006) investigated the effect of different voltage gradients (0, 10, 20, 30, 40, 50 V) of ohmic cooking on the TBARS levels of hamburger patties. They argued that thermal process can promote lipid oxidation by distrupting cell membranes and releasing prooxidants. They defined that increasing voltage gradient tended to increase the TBARS levels. Also higher voltage level as 50 V increased the lipid oxidation in all patties. Piette et al. (2004), studied the bologna samples where they applied ohmic cooking and reached to a fixed target temperature (70 °C), with 3 different voltage densities (2.9, 3.5, and 4.7 V cm^{-1}). They observed that higher ohmic voltage values caused faster heating rates. Higher heating rates facilitate free radical production, greatly accelerating the lipid oxidation.

Table 3.15 Lipid oxidation value of ohmic cooked beef

Ohmic Cooking (Volt)	TBARS (mg MDA/kg)
Raw meat	0.31 ± 0.03^{a}
40	0.59 ± 0.03^{b}
55	0.87 ± 0.07^{c}
70	1.30 ± 0.03^{d}

Different small letters; a, b, c indicate statistical difference between voltage gradient values of ohmic cooking at α=0.05 level

In infrared cooking alone process, TBARS values were ranged between 0.34 and 2.45 mg MDA/kg and increasing temperature caused to increase TBARS value significantly (P < 0.05) (Table 3.16). Infrared is a form of electromagnetic energy that can cause heating on the surface of objects when absorbed (Huang and Sites, 2012). Exposing a beef muscle to an infrared heating source results in an increase in the surface temperature, and the heat is conducted to the interior by conduction (Cummins and Lyng, 2017a). The increase of infrared temperature results higher heating rates and heat fluxes and this could promote lipid oxidation.

Table 3.16 Lipid oxidation value of infrared cooked beef

Infrared Cooking (°F) (core temp. 72 °C)	**TBARS (mg MDA/kg)**
Raw meat	0.34±0.10^{a}
325	1.81±0.32^{b}
375	1.94±0.39^{c}
425	2.45±0.68^{d}

Different small letters; a, b, c indicate statistical difference between infrared cooking temperature values at α=0.05 level

At consecutive application of ultrasound treatment with ohmic cooking, TBARS values of beef samples were ranged between 0.32 and 1.68 mg MDA/kg which were higher than ohmic cooking alone and lower than infrared cooking alone for TBARS values. The increase of ultrasound treatment time cause a significant effect on TBARS value of beef samples. The highest TBARS values were obtained at ultrasound treatment interactions with 70 V ohmic cooking (Table 3.17). Pohlman et al. (1997b) emphasized that the effects of ultrasound-assisted cooking appear as longer sarcomeres, larger diameter fibres and more myofibrillar disruption and shattering of muscle. Thus, ultrasound pre-treatment prepares the beef for efficient ohmic cooking process. In this way, uniform heating acceleration and increased cooking yield could caused to lipid oxidation increment.

Table 3.17 Lipid oxidation value of ultrasound - ohmic cooked beef

Ultrasound (min.)	Ohmic (Volt)	TBARS (mg MDA/kg)
0	untreated	0.32±0.09[a]
10	40	0.69±0.21[b]
20		0.89±0.25[c]
30		1.25±0.32[d]
0	untreated	0.32±0.09[a]
10	55	1.02±0.36[b]
20		1.27±0.28[c]
30		1.32±0.28[d]
0	untreated	0.32±0.09[a]
10	70	1.48±0.47[b]
20		1.61±0.25[c]
30		1.68±0.25[d]

Different small letters; a, b, c indicate statistical difference between ultrasound treatment time values at each same voltage gradient at α=0.05 level

During consecutive application of ohmic and infrared cooking, at constant voltage level, increasing infrared temperature caused significant ($P<0.05$) increase in TBARS value. As it is given in Table 3.18, higher TBARS values were obtained from consecutive application of ohmic-infrared cooking compared to ohmic cooking alone process. This could be due to the exposure of meat surface to higher temperatures and the cooperative effects of thermal damage to the membrane phospholipids and heat denaturation of proteins during ohmic- infrared temperature (Zell et al., 2009). Ohmic-infrared cooking process caused higher TBARS formation in beef meat especially at 70 Volt. Using 40 and 55 Volt values for ohmic cooking alone and 40 V-325 °F, 40V-375 °F for ohmic-infrared cooking is much better to keep the TBARS value below the generally acceptable threshold level.

Table 3.18 Lipid oxidation value of ohmic - infrared cooked beef

Ohmic (Volt)	Infrared (°F)	TBARS (mg MDA /kg)
0	untreated	0.31±0.03^{a}
40	40	0.74±0.14^{b}
	55	1.02±0.07^{c}
	70	1.33±0.07^{d}
0	untreated	0.31±0.03^{a}
55	40	1.10±0.03^{b}
	55	1.30±0.02^{c}
	70	1.41±0.03^{d}
0	untreated	0.31±0.03^{a}
70	40	1.56±0.03^{b}
	55	1.69±0.03^{c}
	70	1.74±0.00^{c}

Different small letters; a, b, c indicate statistical difference between infrared temperature values at each same voltage gradient at α=0.05 level

At consecutive application of ultrasound, ohmic and infrared cooking process, in other words in hybrid cooking, TBARS values were ranged between 0.76 and 5.47 mg MDA/kg for cooked beef samples (Figure 3.36). The highest TBARS values were obtained at consecutive application of 30 minute ultrasound pretreatment, ohmic voltage levels of 40, 55 and 70 V and at 425 °F infrared temperature. In this way, the synergistic effect of hybrid cooking system promote lipid oxidation. Broncano *et al*. (2009) emphasized that there are many studies available demonstrating in different kind of cooked meat has higher levels of TBARS in comparison to the raw meat. Broncano *et al*. (2009) studied the influence of different cooking methods [grilled (GR), fried (FP), microwaved (MW) and roasted (RO)] on lipid oxidation, they found TBARS value of 0.26 mg MDA/kg for raw, 0.86 mg MDA/kg for grilled, 1.19 mg MDA/kg for fried 1.03 mg MDA/kg for microwave, 1.35 mg MDA/kg for roasted *Latissimus dorsi* muscle of Iberian pigs. Soladoye *et al*. (2017) reported that the average TBARS value in the raw bacon was about 0.19 mg MD/kg and increased over threefold and fourfold after microwave and frying pan cooking (0.69 and 0.93 mgMD/kg), respectively.

In our study, ohmic cooking alone, ultrasound-ohmic, ohmic-infrared at 40 and 55 Volt, ultrasound-ohmic-infrared cooking at 10 minute ultrasound treatments with 40, 55, 70 V and 325 and 375 °F infrared cooking TBARS results were closer to Broncano et al. (2009)'s study. However, infrared cooking alone, ohmic-infrared cooking at 70 V, ultrasound-ohmic-infrared at 20 and 30 minute cooking treatments had higher TBARS formation. Cooking process is gaining importance at this point. Maillard *et al*. (1996) indicated that lipid oxidation could decrease the nutritional value by the formation of potentially toxic products during cooking and processing. Wu *et al*. (1991) reported that generally off-odours are formed when the TBARS value is higher than 1 mg/kg and it is regarded as the beginning of organoleptic perceptibility of lipid oxidation and also meat products that have TBARS value higher than 1 mg/kg could be considered as "rancid". In this case, using 40 and 55 Volt values for ohmic cooking alone, 10 min.-40 V, 20 min.-40 V for ultrasound-ohmic cooking, 40 V-325 °F, 40V-375 °F for ohmic-infrared cooking, 10 min.-40 V-325 °F, 10 min.-40 V-375 °F for hybrid process is much better to keep the TBARS value below this generally acceptable threshold level.

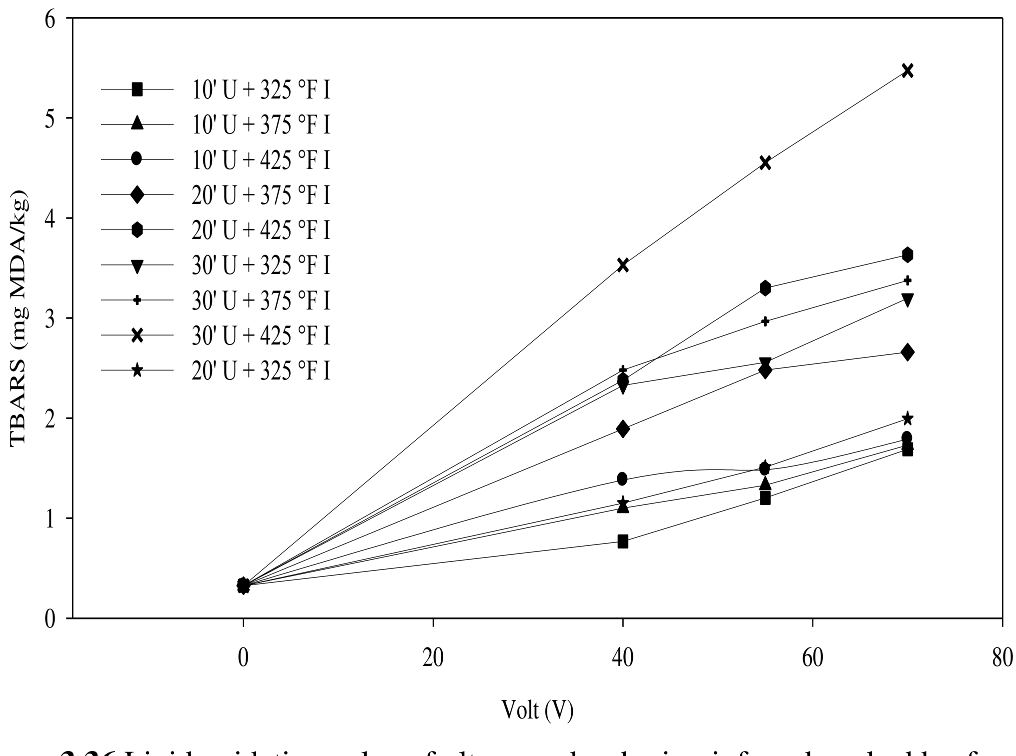

Figure 3.36 Lipid oxidation value of ultrasound - ohmic - infrared cooked beef
Abbreviations: ': minute; U: Ultrasound; °F: Fahrenheit Degree; I: Infrared.

3.6 Total Aerobic Mesophilic Bacteria (TAMB) and Total Coliform (TC) Counts

Total aerobic mesophilic bacteria (TAMB) and total coliform (TC) counts could give an idea about the general hygiene of beef muscle. In this study, TAMB and TC counts of ohmic, infrared, ultrasound-ohmic, ohmic-infrared and ultrasound-ohmic-infrared cooked beef samples were followed during the cooking process (Figures 3.37 - 3.41).

At ohmic cooking alone, TAMB and TC counts in raw beef were found to be 5.73 and 5.01 log cfu/g, respectively. As it is seen in the Figure 3.37, TAMB count significantly decreased ($P<0.05$) to 4.02 log cfu/g, TC count decreased to zero value by increasing voltage level. There are few studies investigating the effects of ohmic cooking on microorganisms in meat and meat products in the literature. Despite the different conditions (Voltage, time) used in these studies compared to our study, as a general, researchers found the reduction in microbial load by ohmic cooking as well as ours. Piette et al. (2004) used ohmic cooking (80 °C/13.78 min and 70 °C/31.44 – 40.36 min total holding time) for inactivation of *Enterococcus faecalis*, inoculated to Bologna type sausages, and obtained a 9.06 log cfu/g reduction in the number of microorganisms. In the same way, İçier et al. (2014) studied ohmic cooking of meatballs at different voltage gradients (15, 20 and 25 V/cm) and holding times (0, 15 and 30 s) in a continuous type ohmic cooker. They observed that, voltage gradient, voltage gradient-holding time was found to be effective. In their study, the initial microbial load of meatball samples by means of TAMB count was found to be 5.83 log cfu/g which close to ours. They investigated that, the reduction achieved was limited in terms of microbiological food safety, it is tolerable for semi-cooked meat balls, which will be further processed by another thermal method. Another challenge study was realized by Zell et al. (2009). They found that whole beef cooked rapidly by ohmic heating (7 fold time reduction) gave levels of quality comparable to those achieved by conventional methods while also reducing cook losses. Moreover, Mitelut et al. (2011) explained as ohmic heating offers an attractive alternative for continuous sterilization of foods containing particulates because it heats simultaneously both the phases of the liquid and particulate mixtures by internal energy generation.

In the standards, no microbiological criteria have been established yet for ohmic cooked meat samples. The Turkish Food Codex (Anon., 2009) allows 5×10^6 cfu/g (6.69 log cfu/g) of TAMB count in raw beef samples but there hasn't been any statement in the codex for cooked meats. However, according to Global Agricultural Information Network (GAIN, 2015) report of "Microbiological Standards for Meat and Meat Products", microbiological requirement for cooked or semicooked meat samples must not be higher than 10^4 cfu/g (4 log cfu/g) of TAMB count. In this study, TAMB count of raw beef samples were in accordance with codex limit. By ohmic cooking, TAMB count was reduced while the TC count of beef completely was destroyed. Accordingly, it was revealed that ohmic cooking is an effective method for reduction of microbial load of meat sample however, it is not adequate alone for killing whole microorganisms of beef meat.

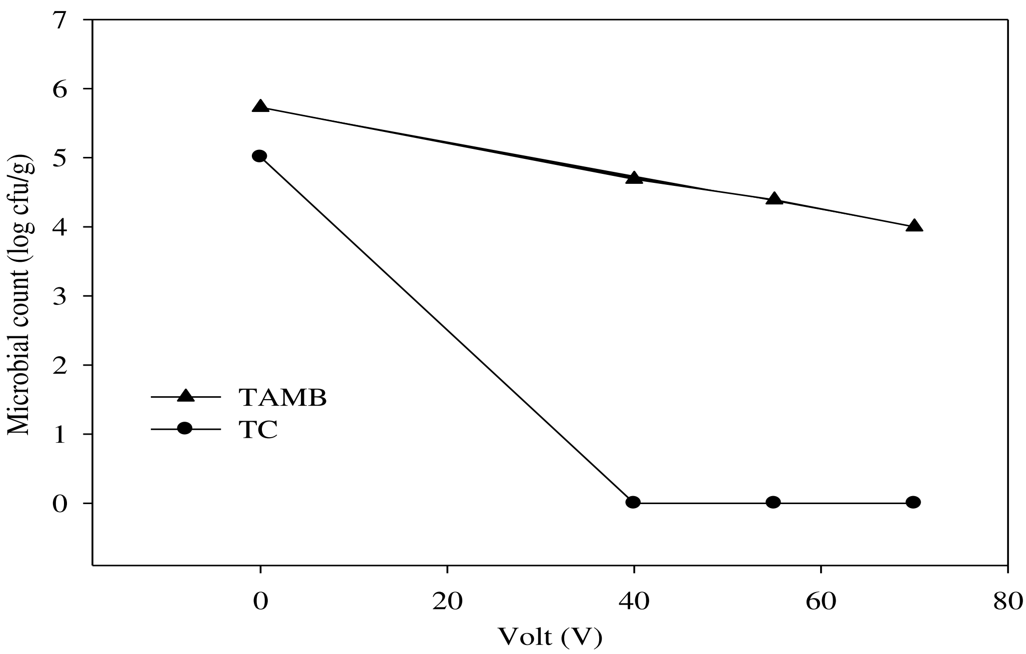

Figure 3.37 TAMB and TC counts of ohmically cooked meat

At infrared cooking alone process, TAMB and TC counts in raw beef meat were found to be 5.02 and 4.62 log cfu/g, respectively (Figure 3.38). In this process, beef meat was cooked until the center temperature reached 72 °C. TAMB count significantly decreased ($P<0.05$) by increasing infrared temperature and it reached to zero value at 425 °F. However, TC count reached to zero value even at 325°F at infrared cooking alone. When compared with ohmic cooking, quite lower TAMB count values were obtained at infrared cooking alone. This could be due to heat transfer to the beef meat is more efficient at infrared cooking. In the literature, there are not many studies about the effect of infrared cooking on microbial load of beef meat. Huang (2004), studied the infrared surface pasteurization of turkey frankfurters and suggested that infrared surface pasteurization potentially could be use as an intervention technology to kill *Listeria monocytogenes* contaminated on the surface of frankfurters immediately prior to final packaging and reduce the risk of foodborne listeriosis caused by these products. Jun et al. (2011) indicated that combinations of infrared heating with microwave heating and other common conductive and convective modes of heating have been gaining momentum because of increased energy throughput.

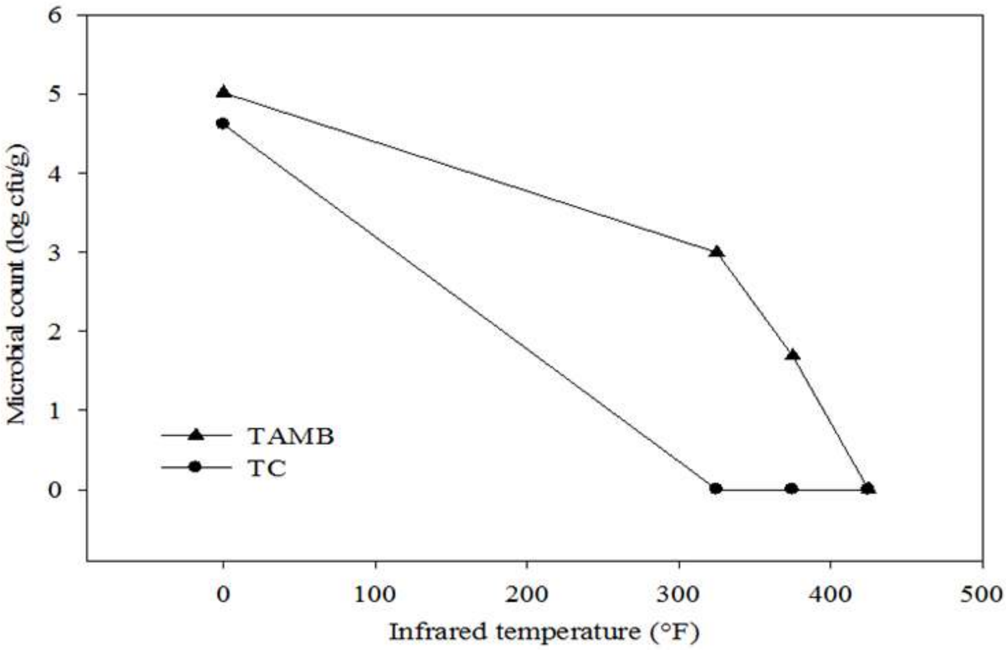

Figure 3.38 TAMB and TC counts of infrared cooked meat

At consecutive application of ultrasound treatment with ohmic cooking, at constant ultrasound time, the increase of voltage level caused a significant decrease of TAMB count values of beef samples but killing whole microorganisms were not realized by this cooking process (Figure 3.39). TAMB count values of beef samples were in the range of 5.81 and 2.54 log cfu/g. The TAMB count values of the ultrasonic-ohmic cooking application of beef were lower than the TAMB count values of the ohmic cooking alone process. According to two way ANOVA results, the interaction of ultrasound and ohmic cooking had a significant effect ($P<0.05$) on TAMB count values of beef muscle. This is because ultrasound could increase the effectiveness of ohmic process by assisting cooking. Moreover, ultrasound can increase the water holding properties of meat and the binding strength which are responsible for increased cooking yield (Reynolds et al., 1978). TC count was decreased to zero value by increasing voltage level as in the process of ohmic cooking alone. In the literature there are no studies about the consecutive application of ultrasound and ohmic cooking process on microbial destruction of beef muscle however there are some researches about the effect of high power ultrasound on the distruption of microorganisms (Baumann et al.,2005; Guerrero et al., 2005; Bermudez-Aguirre et al., 2009). Awad et al. (2012) also indicated that for improving microbial inactivation in foods, ultrasound is combined with other treatments such as pressure, heat and antimicrobials. These treatments are more energy-efficient and effective in killing microorganisms compared to high power ultrasound alone.

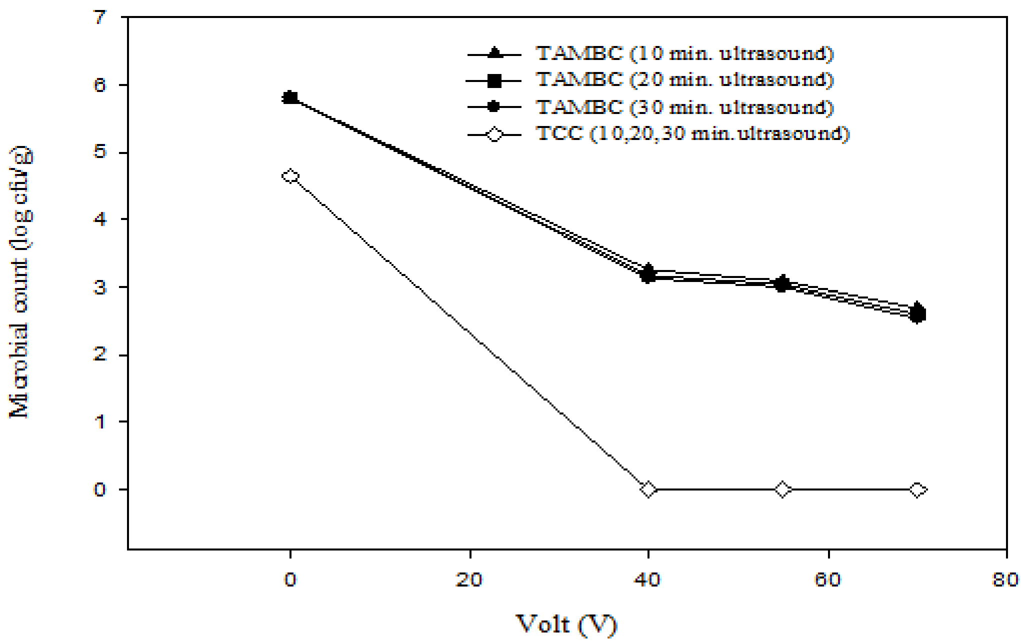

Figure 3.39 TAMB and TC counts of ultrasound- ohmic cooked meat at constant ultrasound time

Consecutive application of ohmic and infrared cooking process have a perfect effect on killing both of whole TAMB and TC counts (Figure 3.40). Only, 40 V and 325 °F (2.47 log cfu/g), 55 V and 325 °F (2.17 log cfu/g) TAMB count couldn't be destroyed completely. It could be said, 325 °F infrared temperature afterwards 40 V and 55 V ohmic cooking was sufficient for reaching microbiological safe level indicated by GAIN (2015) however insufficient to kill microorganisms completely. At this interactive application of cooking process, infrared temperature should be higher than 325 °F in terms of killing all aerobic mesophilic microorganisms. Ohmic cooking followed by infrared cooking technique is more effective by killing total aerobic mesophilic and total coliform bacterias than ohmic cooking alone. Because, in ohmic followed by infrared cooking not only reduction in microorganisms but also killing whole micrорganisms is succeed. There are no studies investigating the effects of ohmic cooking followed by infrared cooking on microorganisms found in meat and meat products in the literature to be able to compare.

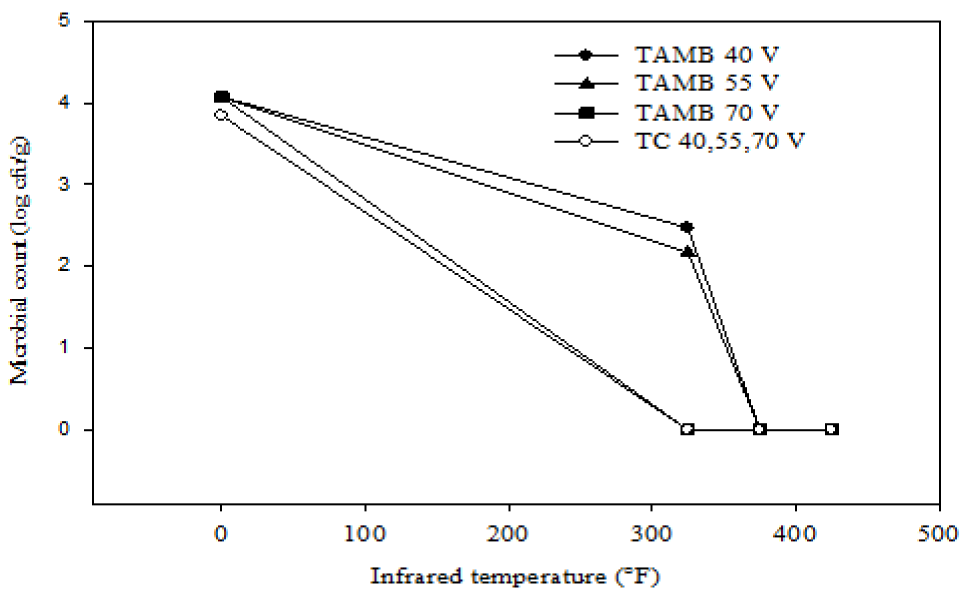

Figure 3.40 TAMB and TC counts of ohmic-infrared cooked meat at constant voltage level

Ultrasound-ohmic-infrared cooking application in other words hybrid cooking process is also succesfull for destroying microorganisms. TAMB and TC counts in raw beef meat were found to be 5.29 and 1.70 log cfu/g, respectively. TC count reached zero value in all samples at the end of cooking process. TAMB count also reached zero value in most samples except 10 min. ultrasound - 40 Volt ohmic - 325 °F infrared (2.90 log cfu/g), 10 min. ultrasound - 55 Volt ohmic -325 °F infrared (1.84 log cfu/g), 10 min. ultrasound - 40 Volt ohmic – 375 °F infrared (1.77 log cfu/g) cooked beef samples (Figure 3.41). This indicated that in the hybrid cooking system, microbiological safe levels indicated by GAIN (2015) had already been reached. However, when working with 10 minute ultrasound time and 325 °F infrared temperature, 70 voltage level should be used to kill whole microorganisms. On the other hand, when working with 10 min. ultrasound time and 375 °F infrared temperature, voltage level should be higher than 40 V to get whole destruction of microorganisms. The rest of the interactions of hybrid cooking system is already safe in terms of microbiological quality of beef muscle and also all total viable counts were destroyed in these interactions.

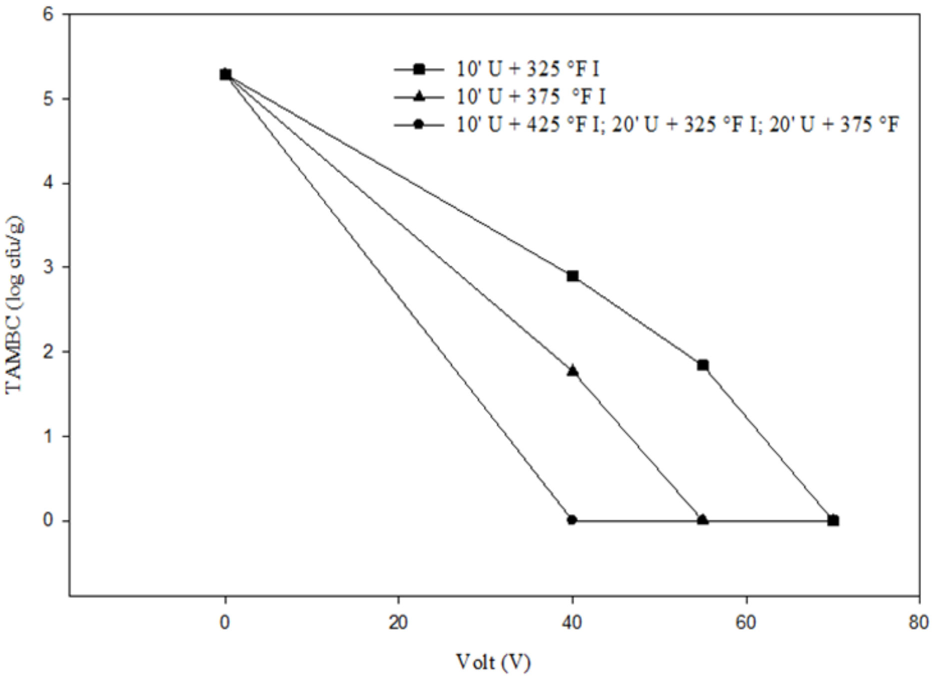

Figure 3.41 TAMB and TC counts of ultrasound- ohmic- infrared cooked meat Abbreviations: ': minute; U: Ultrasound; °F: Fahrenheit Degree; I: Infrared

All of the applications carried out in this study revealed that ohmic cooking appears to be an effective method for reducing the microbial load but it was not be an adequate method by itself to ensure killing all microorganisms in beef muscles from the stand point of best microbiological quality. In this way, hybrid system; combination of ohmic cooking with other treatments in other words, was better to provide best microbiological safety and quality exactly while cooking process of beef muscles with compared to ohmic cooking alone process.

It has to be known that microorganisms are always grow on fresh meat and the ingredients used in the preparation and, they are able to grow on meat products. That is exactly why cooking plays a major role for the shelf life extending of these products by killing of spoilage organisms (Sun, 2006). Ensuring safety of beef muscle from the microbiological point of view is very significant. At this point, cooking system gains importance. There are many effective cooking methods, however, they require high temperatures and long time durations that cause to nutritional and sensory deterioration of beef muscle. Hybrid cooking system used in this study is quite succesfull for killing microorganisms in beef as well as having a lower energy-consumption and shorter process time. There is one product namely "Doner kebab" which is the most consumed traditional ready to eat meat product in Turkey that has also shorter process time. In the cooking system of doner, raw doner is fixed on a vertical spit and slowly rotated to roast the surface evenly, in front of a heating element powered by electric, gas or charcoal, and it is cut into thin slices as it is gradually broiled (Kayışoğlu et al., 2003). There are some studies about the investigation of microbiological quality of beef doner kebabs. Kayışoğlu et al. (2003) determined average TAMB count as 5.68 and 4.92 log cfu/g, average TC count as 4.91 and 3.35 log cfu/g in raw and cooked doner samples respectively. In the work of Flemming et al. (1986), average TAMB count ranged from 10^2 to 10^6 cfu/g in cooked doners. The level of TAMB count per g was between $10^5$and 10^7 cfu/g in the study of Todd et. al. (1986). In another work, Ayaz et al. (1985) found counts of TAMB in the range of 10^2 to 10^8 cfu/g. In despite of beef shape, size and cooking systems are different between hybrid system and döner kebab, when it is compared from the standpoint of microbial load of cooked beef muscles, it is noticed that the hybrid cooking system is superior and advantegous.

3.7 Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are formed as a result of incomplete combustion of organic products. Meat can be contaminated with PAHs mainly during the cooking process. Therefore, it is important to evaluate the formation of PAHs in beef due to different cooking methods and suggest safe cooking methods (Park *et al.,* 2017). In this study, PAHs values of ohmic, infrared, ultrasound-ohmic, ohmic-infrared and ultrasound-ohmic-infrared cooked samples were followed during the cooking process. The change in

PAHs values and statistical analysis results (one way ANOVA) are shown in the Tables 3.19 - 3.22 and Figures 3.42 – 3.44.

Each detected PAHs level of ohmically cooked samples were found between 0.0233-2.8306 μg/kg (Table 3.19). The detected PAH compounds were 1-methylnapthalene, fluorene, anthracene and benzo(a)pyrene at different levels. Voltage gradient had no significant effect (P>0.05) on these PAHs levels of ohmically cooked beef samples. The most abundant PAH was the benzo(a)pyrene (BaP) with up to 1.2690 μg/kg levels among all detected PAHs. BaP is very good indicator for other PAHs in food items; the correlation coefficient reported as 0.87 between total PAHs and BaP level and as 0.98 between the carcinogenic PAHs and BaP level (Kazerouni *et al*., 2001; Reinik *et al*., 2007). According to European Commission (EC) regulation, maximum acceptable levels of BaP in smoked meat and smoked meat products was reported as 5 μg/kg until 31.08.2014 but as from 01.09.2014 maximum acceptable level is 2 μg/kg (EC, 2011). Since no limits have been suggested yet by EC for meat products cooked by other techniques, evaluations were made according to EC limit for smoked meat and smoked meat products. The BaP levels of ohmically cooked beef samples determined in the present study were very lower than EC limits. PAH4 is the sum content of four PAH compounds as; benzo(a)pyrene, chrysene, benz(a)anthracene and benz(b)fluoranthene. PAH4 levels of ohmically cooked meat samples in this study were found to be between 1.2514- 1.2690 μg/kg as shown in Table 4.19. Öz and Yüzer (2016) studied the effect of type of barbecue and cooking levels on the formation of PAHs in beef steak. They found the PAH4 levels range between not detected and 1.30 ng/g. The PAH4 results of our study was lower than the EC PAHs limits. According to EC directives, the maximum limit of PAH4 for smoked meat and smoked meat products is 12 μg/kg (EC, 2011). The total PAH contents of ohmically cooked beef samples varied between 2.5685 and 2.8306 μg/kg. This is relatively low in comparison with the study of Duedahl-Olesen et al. (2006). They examined the smoked meat samples produced in Denmark and found the sum of PAH in smoked meat products ranged from 24 μg/kg for salami to 64 μg/kg in bacon.

Each detected PAHs level of infrared cooked samples were found between 0.2571 – 9.0371 µg/kg which were slightly higher than PAHs levels of ohmically cooked sample (Table 3.20). The detected PAH compounds for infrared cooked samples were 1-methylnapthalene, 2-methylnapthalene, acenapthylene, fluorene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene and benzo(a)pyrene at different levels. Cooking at 375 °F infrared temperature caused a significant increase on the level of benz(a)anthracene and total PAHs while 425 °F infrared temperature caused a significant increase on the level of 1-methylnapthalene and anthracene. High-temperature cooking increased PAHs levels in meat. Cooking and food processing at high temperatures have been shown to generate various kinds of PAHs (Agerstad and Skog, 2005). On the other hand, in this study, increment infrared temperature did not cause a significant effect for other detected PAHs of infrared cooked beef samples. Lijinsky (1991) indicated that PAHs form on or near the surface of meats rather than in the interior, foods cooked without being exposed to smoke do not show significant levels of PAH. B(a)P levels of infrared cooked samples were ranged between 1.2599 – 1.2643 µg/kg which were lower than EC limits and findings of some studies. Farhadian et al. (2010) studied the occurrence of PAHs in Malaysian grilled meat dishes and they evaluated B(a)P for beef satay as 7.34 -12.5 µg/kg. PAH4 and total PAH levels of infrared cooked samples were higher than ohmically cooked ones. This could be due to higher temperatures reaches at the surface facilitating during infrared cooking compared to the ohmic cooking process (Sing et al., 2016). In 2008, EFSA published an opinion on PAHs (EFSA, 2008) and concluded that BaP alone was not a suitable general marker for PAHs in food, but identified a group of 4 PAHs (PAH4) as better indicators based on data relating to occurrence and toxicity. PAH4 levels of infrared cooked samples were ranged between 3.5361 – 3.6327 µg/kg. Rose et al. (2015) investigated the effect of frying, grilling, barbecuing, toasting and roasting on the formation of PAHs in foods and they found PAH4 levels in beef samples up to level of 10.87 µg/kg in beef burgers up to level of 95.87 µg/kg for all treatments. PAH4 levels of infrared cooked beef samples detected in the present study were found to be lower in comparison with the study carried by Rose et al. (2015).

Table 3.19 Levels of PAHs (μg/kg) of only ohmic cooked samples

PAHs (μg/kg)	40 V	55 V	70 V
Raw	ND	ND	ND
Napthalene	ND	ND	ND
1-Methylnapthalene	0.7933±0.0368[a]	0.8311±0.0045[a]	0.9884±0.1180[a]
2-Methylnapthalene	ND	ND	ND
Acenapthylene	ND	ND	ND
Fluorene	0.0233±0.0326[a]	0.0061±0.0043[a]	0.0657±0.0871[a]
Phenanthrene	ND	ND	ND
Anthracene	0.5005±0.0191[a]	0.5056±0.0111[a]	0.5075±0.0118[a]
Fluoranthene	ND	ND	ND
Pyrene	ND	ND	ND
Benz (a) anthracene	ND	ND	ND
Chrysene	ND	ND	ND
Benzo (a) pyrene	1.2514±0.3258[a]	1.2574±0.0703[a]	1.2690±0.3258[a]
PAH4	1.2514±0.0739[a]	1.2574±0.0704[a]	1.2690±0.3258[a]
∑PAH	2.5685±0.0147[a]	2.6002±0.0594[a]	2.8306±0.2832[a]

Different small letters; a, b, c indicate statistical difference between voltage gradient values of ohmic cooking at α=0.05 level. Abbreviations: ND: Not determined.

Table 3.20 Levels of PAHs (µg/kg) of only infrared cooked samples

PAHs (µg/kg)	325 °F	375 °F	425 °F
Raw	ND	ND	ND
Napthalene	ND	ND	ND
1-Methylnapthalene	0.9071±0.0669^{a}	1.2446±0.0737^{a}	2.3925±0.4728^{b}
2-Methylnapthalene	ND	0.3984±0.0070	0.3994±0.0000
Acenapthylene	ND	1.3459±0.0114	1.0348±0.1368
Fluorene	0.2571±0.1425^{a}	0.4229±0.1199^{a}	0.4519±0.0763^{a}
Phenanthrene	ND	ND	ND
Anthracene	0.4781±0.0027^{a}	0.4796±0.0028^{a}	0.5074±0.0016^{b}
Fluoranthene	ND	0.6243±0.0021	0.6197±0.0107
Pyrene	ND	ND	ND
Benz (a) anthracene	0.8898±0.0029^{a}	0.9127±0.0059^{b}	0.9129±0.0058^{b}
Chrysene	1.3863±0.0045^{a}	1.4122±0.0100^{ab}	1.4554±0.0253^{b}
Benzo (a) pyrene	1.2599±0.0363^{a}	1.2640±0.1536^{a}	1.2643±0.3656^{a}
PAH4	3.5361±0.0438^{a}	3.5890±0.1576^{a}	3.6327±0.3345^{a}
∑PAH	5.1785±0.1630^{a}	8.1049±0.3473^{b}	9.0371±0.8555^{b}

Different small letters; a, b, c indicate statistical difference between infrared temperature values of ohmic cooking at α=0.05 level. Abbreviations: ND: Not determined.

At consecutive application of ultrasound treatment and ohmic cooking, each detected PAHs levels were found to be between 0.0657 and 4.9202 µg/kg (Table 3.21). As a general, the increase of ultrasound treatment time at each voltage level did not cause a significant effect on PAH levels of beef sample. However, at consecutive application of ultrasound treatment and ohmic cooking, more PAH compunds unlike ohmic cooking were detected such as 2-Methylnapthalene, acenapthylene, phenanthrene, benz(a)anthracene, chrysene. Moreover, at 40 V ohmic treatment the increase of ultrasound treatment to 30 min. caused a significant increase in PAH4 level of beef sample. This could be due to that ultrasound treatment assists cooking, increases the water holding properties of meat and the binding strength which are responsible for increased cooking yield (Reynolds et al., 1978).

At consecutive application of ohmic and infrared cooking, each detected PAHs levels of sample were found between 0.0233 and 2.9941 µg/kg (Table 3.22). It can also be observed that 1-methylnapthalin, fluorene, anthracene and benzo(a)pyrene were detected at different levels in almost all samples treated with ohmic cooking followed by infrared cooking. However, the other PAHs were not determined in ohmic cooking alone and detected in lower levels at consecutive application of ohmic and infrared cooking. In this sense, lower center temperature reached and direct energy application of ohmic cooking alone makes it safer for the PAH formation compared to the consecutive application of ohmic and infrared cooking method.

PAH4 levels of the ohmic followed infrared cooked meat samples in this study were found to be between 1.2887- 3.7849 µg/kg as shown in Table 3.22. Kendirci et al. (2014) determined PAH4 levels between 0.62- 6.21 µg/kg in meatball samples treated with ohmic cooking combined with infrared heating using different fluxes, distances and durations. Jira (2010) studied PAH in representative samples of smoked meat products (raw sausages, raw ham, cooked ham, frankfurter-type sausage, liver sausages) in Germany. PAH4 levels were observed in frankfurter-type sausages as a median value of 0.6 µg/kg which was the highest, in the range of 0.3 µg/kg in raw ham and liver sausages, 0.2 µg/kg median value in raw sausages and the lowest median value 0.1 µg/kg in cooked ham. Öz and Yüzer (2016) found that the PAH4 levels ranged between not detected and 1.30 ng/g in barbecued beef steak. The

PAH4 results of our study were higher than these values but lower than the EC PAH4 limit.

The total PAH contents of consecutive application of ohmic and infrared cooked beef samples varied between 3.6001 and 13.6536 µg/kg. This is relatively low in comparison with the study of Kendirci et al. (2014). They examined the effects of infrared cooking on polycyclic aromatic hydrocarbon (PAH) formation in ohmically pre-cooked beef and found the sum of PAH in meat products ranged between 4.47 and 64 µg/kg. Also, Elhassaneen (2004) studied the broiling of beef burgers by use of charcoal and detected 11 PAHs that were in the range of 0.31-14.95 mg/ kg. Panalaks (1976) indicated that barbecued meat had the greatest PAHs level that were 164 µg/kg in the point of total PAHs and 30 µg/kg in the point of benzo(a)pyrene. In this present study, it can be observed from Table 3.22, the consecutive application of ohmic and infrared cooking caused lower levels of BaP (1.25–1.43 µg/kg) formation than EC limits that were stated before. In general, PAH levels of cooked beef meat reached to the maximum values at high ohmic voltage level and high infrared temperature values in this study.

Table 3.21 Levels of PAHs (µg/kg) of ultrasound-ohmically cooked samples

Ultrasound Treatment (min.)	Ohmic Cooking (Volt)	Napthalene	1-Methylnapthalene	2-Methylnapthalene	Acenapthylene	Fluorene	Phenanthrene	Anthracene
Raw		ND	ND	ND	ND	ND	ND	ND
10		ND	ND	0.7124±0.1976	2.7534±0.9890	ND	0.1883±0.0008	ND
20	40	ND	0.7816±0.0631	ND	ND	0.2059±0.2777	0.1903±0.0017	ND
30		ND	ND	ND	ND	0.1301±0.0806	ND	ND
Raw		ND	ND	ND	ND	ND	ND	ND
10		ND	ND	ND	ND	ND	ND	ND
20	55	ND	ND	ND	ND	ND	ND	ND
30		ND	ND	ND	ND	0.1131±0.0593	ND	ND
Raw		ND	ND	ND	ND	ND	ND	ND
10		ND	0.7678±0.3119	ND	ND	0.0657±0.0645	ND	ND
20	70	ND	ND	ND	ND	ND	ND	ND
30		ND	ND	ND	ND	0.1051±0.0628	ND	ND

Table 3.21 continued

Ultrasound Treatment (min.)	Ohmic Cooking (Volt)	Fluoranthene	Pyrene	Benz (a) anthracene	Chrysene	Benzo (a) pyrene	PAH4	∑PAH
Raw		ND	ND	ND	ND	ND	ND	ND
10		ND	ND	ND	ND	1.2658±0.0699^{a}	1.2658±0.0699^{a}	4.9202±1.1158^{a}
20	40	ND	ND	ND	ND	1.3087±0.0071^{a}	1.3087±0.0071^{a}	2.4868±0.3355^{b}
30		ND	ND	0.8955±0.0077	1.3909±0.0200	1.3143±0.1673^{a}	3.6009±0.1796^{b}	3.7311±0.0989^{ab}
Raw		ND	ND	ND	ND	ND	ND	ND
10		ND	ND	ND	ND	1.2686±0.1527^{a}	1.2686±0.1527^{a}	1.2686±0.1527^{a}
20	55	ND	ND	ND	ND	1.3015±0.1089^{a}	1.3015±0.1089^{a}	1.3015±0.1089^{a}
30		ND	ND	ND	ND	1.3237±0.0828^{a}	1.3237±0.0828^{a}	1.4370±0.0235^{a}
Raw		ND	ND	ND	ND	ND	ND	ND
10		ND	ND	ND	ND	1.2859±0.0761^{a}	1.2859±0.0761^{a}	2.1195±0.3235^{a}
20	70	ND	ND	ND	ND	1.3062±0.2182^{a}	1.3062±0.2182^{a}	1.3062±0.2182^{b}
30		ND	ND	ND	ND	1.3344±0.0744^{a}	1.3344±0.0744^{a}	1.4396±0.0116^{ab}

Table 3.22 Levels of PAHs (µg/kg) of ohmic-infrared cooked samples

Ohmic Cooking (Volt)	Infrared Cooking (°F)	Napthalene	1-Methylnapthalene	2-Methylnapthalene	Acenapthylene	Fluorene	Phenanthrene	Anthracene
Raw		ND	ND	ND	ND	ND	ND	ND
40	325	ND	0.9134±0.0489^{a}	ND	ND	ND	ND	0.5080±0.0039^{a}
	375	ND	1.0511±0.0601^{ab}	ND	ND	0.0293±0.0240	ND	0.5099±0.0141^{a}
	425	ND	1.3514±0.1894^{b}	ND	ND	0.2876±0.1303	ND	0.5967±0.0083^{b}
Raw		ND	ND	ND	ND	ND	ND	ND
55	325	ND	1.0203±0.3833^{a}	ND	ND	ND	ND	0.5281±0.0197^{a}
	375	ND	1.1462±0.2322^{a}	ND	ND	0.0948±0.0826	ND	0.5822±0.0042^{b}
	425	ND	2.3287±0.1759^{b}	0.4104±0.0063	ND	0.0230±0.0283	ND	0.6820±0.0115^{c}
Raw		ND	ND	ND	ND	ND	ND	ND
70	325	ND	1.6086±0.4720^{a}	0.4106±0.0048^{a}	ND	0.9784±0.4577^{a}	0.2017±0.0144^{a}	0.5427±0.0280^{a}
	375	ND	2.8416±0.2255^{a}	0.4131±0.0140^{a}	1.2521±0.1306^{a}	1.1963±0.2241^{a}	0.2020±0.0109^{a}	0.6000±0.0034^{b}
	425	0.22±0.0666	2.9941±0.9155^{a}	0.4180±0.0133^{a}	2.4021±0.0653^{b}	1.5949±1.1548^{a}	0.2059±0.0279^{a}	0.6961±0.0122^{c}

Table 3.22 continued

Ohmic Cooking (Volt)	Infrared Cooking (°F)	Fluoranthene	Pyrene	Benz (a) anthracene	Chrysene	Benzo (a) pyrene	PAH4	∑PAH
Raw		ND	ND	ND	ND	ND	ND	ND
40	325	ND	ND	0.8919±0.0013^{a}	ND	1.2868±0.0416^{a}	2.1787±0.0403^{a}	3.6001±0.0853^{a}
	375	0.6264±0.0018	ND	0.8938±0.0005^{a}	ND	1.3025±0.0053^{a}	2.1963±0.0058^{a}	4.4130±0.0260^{ab}
	425	0.6325±0.0012	ND	0.8974±0.0039^{a}	ND	1.4086±0.1372^{a}	2.3060±0.1411^{a}	5.1742±0.4704^{b}
Raw		ND	ND	ND	ND	ND	ND	ND
55	325	ND	ND	ND	ND	1.2887±0.0598^{a}	1.2887±0.0598^{a}	2.8371±0.3039^{a}
	375	0.6301±0.0028	ND	ND	ND	1.3040±0.1842^{a}	1.3040±0.1842^{a}	3.7573±0.1377^{b}
	425	0.6387±0.0080	ND	0.8908±0.0050	ND	1.4227±0.0106^{a}	2.3135±0.0156^{b}	6.3963±0.1577^{c}
Raw		ND	ND	ND	ND	ND	ND	ND
70	325	0.5848±0.0191^{a}	0.6856±0.0238^{a}	0.9033±0.0179^{a}	1.3861±0.0018^{a}	1.3106±0.1200^{a}	3.6000±0.1038^{a}	8.6124±0.0472^{a}
	375	0.6455±0.0097^{b}	0.6872±0.0014^{a}	0.9046±0.0167^{a}	1.4099±0.0100^{a}	1.3118±0.3378^{a}	3.6263±0.3111^{a}	11.4641±0.4603^{b}
	425	0.6520±0.0027^{b}	0.6886±0.0006^{a}	0.9072±0.0219^{a}	1.4385±0.0085^{a}	1.4392±0.1027^{a}	3.7849±0.0722^{a}	13.6536±0.0095^{c}

At consecutive application of ultrasound, ohmic and infrared cooking, the detected PAHs were naphthalene, 1-methylnapthalene, 2-methylnapthalene, acenapthylene, fluorene, phenanthrene, anthracene, fluoranthene, benz(a)anthracene, chrysene, benzo(a)pyrene at different levels as seen in the Figures 3.42 – 3.44. in beef samples.

Naphthalene was observed as the most abundant one among all PAHs with up to 25 µg/kg levels (Figure 4.42). As a general, at constant ultrasound treatment time and ohmic process voltage level the increase of infrared temperature caused less Naphthalene formation. These findings are relatively close to the study of Kendirci et al. (2014). They found also Naphthalene was observed as the most abundant PAH detected (up to 40 µg/kg) for their study which is ohmic cooking combined with infrared cooking of meat and they observed least amount of Naphthalene at higher heat flux, distance and duration value of infrared system. They reported that at higher temperatures the crust formed inhibited migration of fat to the surface thereby reduce the PAH formation. Naphthalene is a flammable white solid with melting and boiling points of 80.5 and 218 °C, respectively. Due to its bicyclic aromatic structure, naphthalene is a polycyclic aromatic hydrocarbon (PAH), and it is the most volatile member of this group (Batterman and Jia, 2010). That's why, at higher temperatures Naphtalene was detected at lower levels in beef samples.

1-methylnapthalene and acenapthalene were the second PAHs at higher levels detected in beef samples which were in the range between not detected-12.6477 µg/kg and not detected-10.8455 µg/kg, respectively. At constant ultrasound time and ohmic voltage level, the increase of temperature caused less formation of 1-methylnapthalene and acenapthylene as in the case of naphtalene. Fluorene was detected in lower amounts (not detected-3.76 µg/kg) with compared to napthalene, 1-methylnapthalene, acenapthylene as seen in the Figure 3.42.

2-methylnapthalene was detected almost in all samples but in lower amounts which was in the range of not detected and 0.5352 µg/kg levels. Phenanthrene, anthracene and benz(a)anthracene were not detected in all samples but found in the samples of 55 V ohmic cooking interactions. Fluoranthene was also not detected in all samples but found up to 0.63 µg/kg levels in some samples. Farhadian et al. (2010) studied the formation of PAHs in Malaysian popular grilled meat dishes and minimum concentration of fluoranthene (3.51 ng/g) was detected in oven grilled chicken, and the maximum concentration (106 ng/g) was detected in beef satay in their study. Chyrsene was detected only in the samples treated at 30 min. ultrasound, 40 V ohmic cooking, 375 °F infrared and 30 min. ultrasound, 55 V ohmic cooking, 325 °F infrared as 1.3930 and 1.3874 µg/kg, respectively. Chung et al. (2011) studies the effects of charcoal grilling, charcoal roasting and gas roasting on the formation of PAHs in commercial meat samples and determined chyresene in the range of 0.03 and 2.42 µg/kg levels.

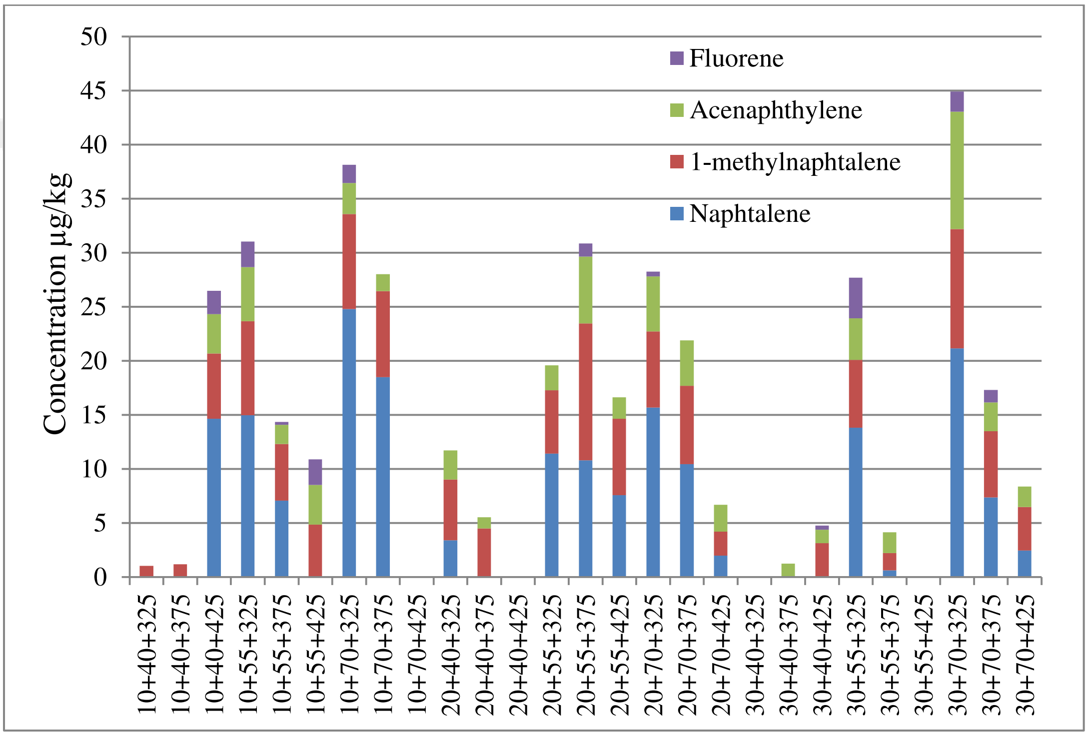

Figure 3.42 Napthalene, 1-methylnapthalene, acenapthylene, fluorene levels of ultrasound-ohmic-infrared cooked beef samples

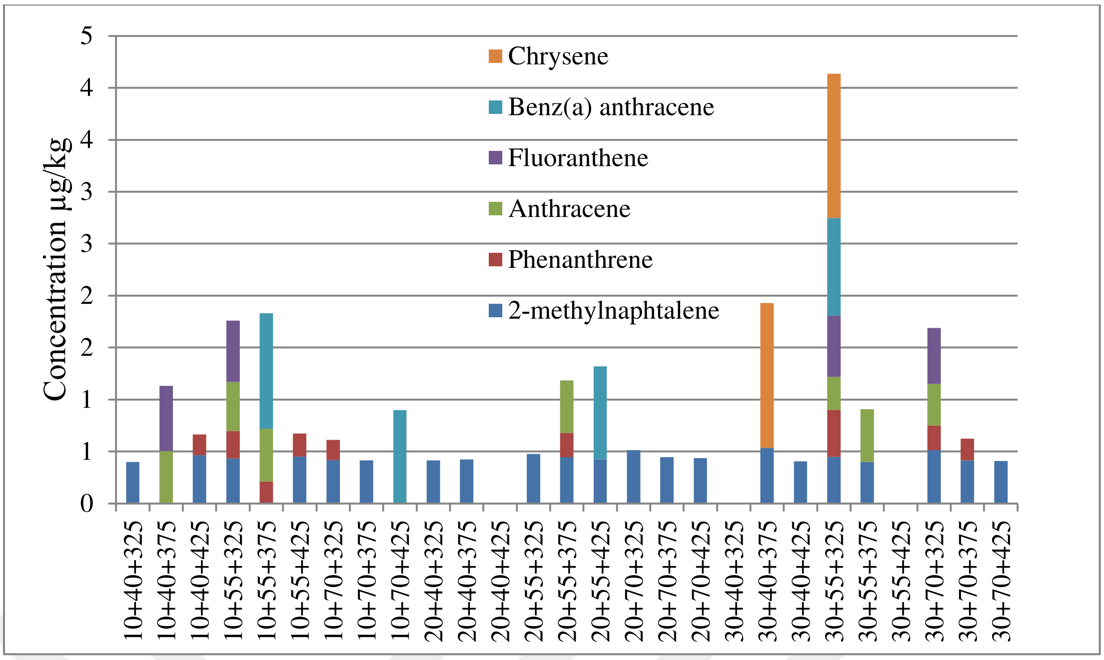

Figure 3.43 2-methylnapthalene, phenanthrene, anthracene, fluoranthene, benz(a)anthracene, chrysene levels of ultrasound-ohmic-infrared cooked beef samples

BaP was detected in the range between 1.3307 and 1.4966 µg/kg in the samples of consecutive application of ultrasound, ohmic and infrared cooking. The minimum BaP level (1.3307 µg/kg) was detected at 10 min. ultrasound - 40 V ohmic – 325 °F infrared cooking while the maximum (1.4966 µg/kg) was detected at 30 min. ultrasound - 70 V ohmic – 425 °F. At constant ultrasound time and ohmic voltage level, infrared temperature increment caused to higher formation of BaP levels. However, BaP levels detected in this study were found to be lower when compared to barbecued beef steaks (0-24 µg/kg) (Aaslyng et al., 2013); grilled beef satay (7.34-12.5 µg/kg) (Farhadian et al. 2010); charcoal and modified charcoal grilled pork belly (8.04 and 1.28 µg/kg) (Park et al., 2017) ; charcoal and gas grilled kebab (24.2 and 5.7 µg/kg) (Terzi et al., 2008). BaP levels in this study were higher than boiled beef samples (1.09 µg/kg) analysed in the study of Martorell et al. (2010). In terms of EC limits, at consecutive application of ultrasound, ohmic and infrared cooking, BaP levels examined were smaller than 2 µg/kg which indicating safety of our cooking system. PAH4 levels were found to be between 1.3307 and 3.7541 µg/kg. Aaslyng et al. (2013) studied the PAH content in meat (pork, chicken and beef) barbecued at home by Danish consumers and found the sum of PAH4 was highest in beef (average

17.3 µg/kg) compared with pork (average 2.6 µg/kg) and chicken (average 1.1 µg/kg). PAH4 levels at consecutive application of ultrasound treatment, ohmic and infrared cooking were also lower than EC limits which were 12 µg/kg for smoked meat (EC, 2011).

At consecutive application of ultrasound, ohmic and infrared cooking, 11 PAH compounds were detected and total PAH levels were in the range between 1.3833 and 48.0399 µg/kg. Maximum total PAH levels were detected at 30 min. ultrasound - 70 V ohmic - 325 °F infrared cooked beef samples. As a general, at constant ultrasound time and ohmic voltage level, with increasing temperature, total PAH level formation decreased in parallel with the decrease of naphthalene. Larsson et al. (1983) studied the levels of 22 PAHs in grilled meat and meat products and their results revealed that PAH levels are strongly dependent on the method of cooking and type of heat source used. High PAH levels were often examined in smoked, grilled and barbecued beef samples. Cooking system namely hybrid system performed in this study due to its low PAHs levels by comparing many other studies can be considered as safe from a PAH contamination point of view.

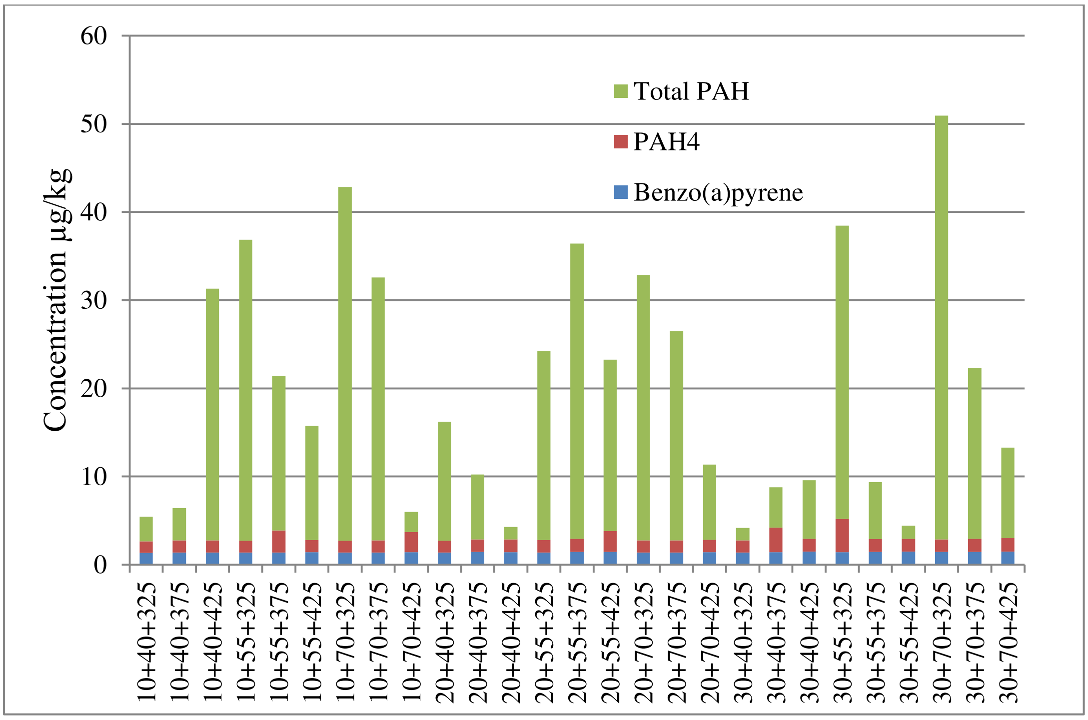

Figure 3.44 BaP, PAH4 and total PAHs levels of ultrasound-ohmic-infrared cooked beef samples

CHAPTER 4

CONCLUSIONS

In this study, the effects of the hybrid cooking on quality and safety attributes of beef muscle were investigated. In this sense, a hybrid cooking system was constitued for beef cooking by the consecutive application of ultrasound (10, 20, 30 min.), ohmic (40, 55, 70 V) and infrared treatments (325, 375, 425 °F). Cooking treatments on moisture content, pH, color, texture, thiobarbituric acid reactive substance (TBARS), total aerobic mesophilic bacteria (TAMB) and total coliform (TC) counts, polycyclic aromatic hydrocarbons (PAHs) values of beef muscle were examined and the following results were obtained.

Moisture Content:

- Moisture content values of the raw beef samples were in the range of 72.29 – 74.98 %.
- Moisture content values of beef samples decreased by ohmic cooking alone, infrared cooking alone, ultrasound-ohmic and ohmic-infrared treatments. However, the lowest moisture content values (51.01–53.15 %) of cooked beef samples were obtained in hybrid system, especially at higher ultrasound time (30 min.), higher ohmic voltage gradient (70 V) and higher infared temperature (425 °F) treatments.
- It could be stated that hybrid system formed a synergistic cooking effect by lowering the moisture content of beef samples.

pH:

- pH values of raw beef samples were measured in the range of 5.42 and 5.65 which refers to highest quality meat.

- At ohmic cooking alone, infrared cooking alone, ultrasound-ohmic and ohmic- infrared treatments pH values were significantly different and higher from raw beef sample pH values.
- At ultrasound-ohmic and ohmic- infrared treatments, it was seen that while ultrasound treatment time did not cause a significant effect on pH value of beef samples, infrared temperature caused a significant effect on pH value, especially at 70 V the increase of infrared temperature caused a significant increase on pH value of beef sample.
- At consecutive application of ultrasound, ohmic and infrared treatment as a general, increase of voltage gradient caused a significant increase on pH value. It could be due to loss of free acidic groups at higher voltage gradients that the current passing through the sample was higher.

Hunter Color Values:

- Color measurements (L*, a*, b*, H and S) were performed on both inside and outside surfaces of only ohmic, only infrared, ultrasound-ohmic, ohmic-infrared and hybrid cooked beef samples.
- Both outside (L*outer, a*outer, b*outer, Houter, Souter) and inside color (L*inner, a*inner, b*inner, Hinner, Sinner) values of all cooked beef samples were significantly different ($P<0.05$) from raw beef sample.
- At ohmic cooking alone process, outer values of L*, a*, b*, H and S were higher than inner values of L*, a*, b*, H and S whereas at infrared cooking alone process L*, a*, b*, H and S outer values were lower than L*, a*, b*, H and S inner values. Because infrared cooking is effective for surface heating of the samples.
- At ultrasound-ohmic and ohmic-infrared treatments, ultrasound treatment was influential to increase the effectiveness of ohmic cooking at some treatments but it could be said that not as effective as the infrared system.
- At consecutive application of ultrasound-ohmic-infrared the lowest values of L* and a* values which indicates the success of hybrid system. Because at ohmic cooking alone process, beef samples had homogeneous brown color but lack of crust layer (higher L* and a* values for outside surface of beef samples). In hybrid system, with the support of ultrasound and infrared

treatment to the ohmic system, cooked crust visual on beef muscle had been accomplished.

Texture:

- Texture profile values (hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience) of only ohmic, only infrared, ultrasound-ohmic, ohmic- infrared and hybrid cooked beef samples were significantly different from ($P<0.05$) raw beef sample.
- Texture profile values of infrared cooked samples were higher than ohmically cooked samples since meat releases more water by infrared treatment.
- At consecutive application of ultrasound treatment with ohmic cooking, the interaction of ultrasound and ohmic treatment cause a significant effect on hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resiliences of beef muscle. This could be due to ultrasound can assist restructuring of meat proteins and tenderising of meat.
- Ohmic-infrared treatment showed same textural behaviour trend as in the ultrasound-ohmic treatment.
- Ultrasound, ohmic and infrared interaction namely hybrid cooking caused a significant effect ($P<0.05$) on hardness, gumminess and resiliences of beef muscle, however, on springiness, cohesiveness and chewiness values it did not cause a significant effect ($P>0.05$).
- As a general, combination of ohmic cooking and infrared cooking with other alternative cooking methods, especially hybrid cooking is considered to be more efficient over ohmic cooking alone or infrared cooking alone since it gives a synergistic effect.

Thiobarbituric acid reactive substance (TBARS):

- In this study, TBARS values of raw beef samples were in the range of 0.31 and 0.34 mg MDA/kg whereas cooked beef samples TBARS values were found between 0.59 – 5.47 mg MDA/kg.
- Voltage gradient and infrared temperature had a significant effect on TBARS value. Higher voltage values and higher temperatures caused faster heating

rates which caused to free radical production, greatly accelerating the lipid oxidation.

- In the treatments, using 40 and 55 Volt values for ohmic cooking alone, 10 min.- 40 V, 20 min.- 40 V for ultrasound-ohmic cooking, 40 V-325 °F, 40V - 375 °F for ohmic-infrared cooking, 10 min.-40 V-325 °F, 10 min.-40 V-375 °F for hybrid process is much better to keep the TBARS value below the generally acceptable threshold level (1 mg/kg).

Total aerobic mesophilic bacteria (TAMB) and Total coliform (TC) counts:

- In this study, TAMB and TC counts in raw beef were found between 4.07-5.81 log cfu/g and 3.84- 5.01 log cfu/g, respectively that were in accordance with codex limits.
- TC count decreased to zero value at the end of cooking process at each processing parameters (ultrasound time, voltage level and infrared temperature) for all cooking treatments (ohmic cooking alone, infrared cooking alone, ultrasound-ohmic, ohmic- infrared and hybrid cooking).
- Destruction of whole TAMB counts could be achieved by mostly hybrid cooking system.
- Ohmic cooking was an effective method for reduction of microbial load of meat sample to reach the safe level however was is not adequate alone for killing whole microorganisms of beef meat.
- When compared with ohmic cooking, quite lower TAMB count values were obtained at infrared cooking alone. Interaction of ultrasound and ohmic cooking also had a significant effect ($P<0.05$) on TAMB count values of beef muscle.
- Consecutive application of ohmic and infrared cooking process, 40 V – 325 °F and 55 V - 325 °F treatments were also sufficient for reaching microbiological safe level however insufficient to kill microorganisms completely.
- When comparing all of the treatments, hybrid cooking process is very succesfull for the destruction of whole microorganisms. In this way, hybrid

system could be said to be very effective to provide best attributes for safety and quality exactly while cooking process of beef muscles.

Polycyclic aromatic hydrocarbons (PAHs):

- In this study, 12 PAHs compounds (napthalene, 1-methylnapthalene, 2-methylnapthalene, acenapthylene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz (a) anthracene, chrysene, benzo (a) pyrene) were detected at different levels of only ohmic, only infrared, ultrasound-ohmic, ohmic- infrared and hybrid cooked beef samples.
- The most abundant PAH was the benzo(a)pyrene (BaP) among all detected PAHs. PAH4, the sum content of four PAH compounds as; benzo(a)pyrene, chrysene, benz(a)anthracene and benz(b)fluoranthene, is also good indicator and suitable general marker for PAHs in beef samples.
- BaP and PAH4 values of only ohmic, only infrared, ultrasound – ohmic, ohmic – infrared and hybrid cooked beef samples were lower than European Commission (EC) regulation limit.
- At hybrid coking system, Naphthalene was observed as the most abundant one among all PAHs with up to 25 μg/kg levels. At higher infrared temperatures lower amount of Naphthalene was detected since it is the most volatile member of PAHs group.
- As a general, hybrid cooking system performed in this study due to its low PAHs levels of beef samples by comparing many other studies can be regarded as safe from a PAH contamination point of view.

As a consequence, in this study, it was observed that at hybrid cooking system, ohmic cooking efficiency increased with the support of ultrasound and infrared treatment. For this reason, hybrid cooking system is a safe and advantegous cooking method compared to ohmic cooking alone and infrared cooking alone with many quality attributes of the meat protected. In this way, more quality and reliable products will be provided to both the economy and the consumer.

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APPENDICES

Table A.1 Retention times (Rt) of 12 PAHs compounds

PAHs	**RT (min.)**
Napthalene	6.224
1-Methylnapthalene	8.058
2-Methylnapthalene	9.727
Acenaphthylene	10.814
Fluorene	16.375
Phenanthrene	19.577
Anthracene	22.757
Fluoranthene	26.927
Pyrene	32.728
Benz(a)anthracene	35.038
Chrysene	39.728
Benzo(a)pyrene	48.312

Abbreviations: PAHs; polycyclic aromatic hydrocarbons, min; minutes

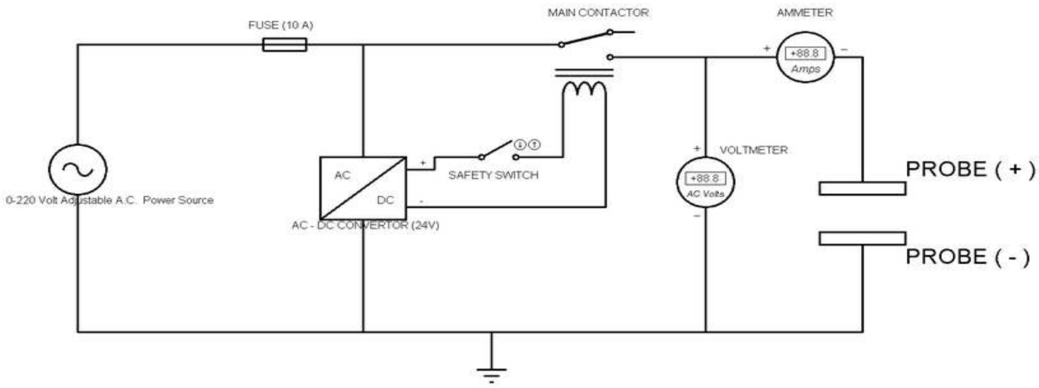

Figure A.1 Ohmic cooking design

<Chromatogram>

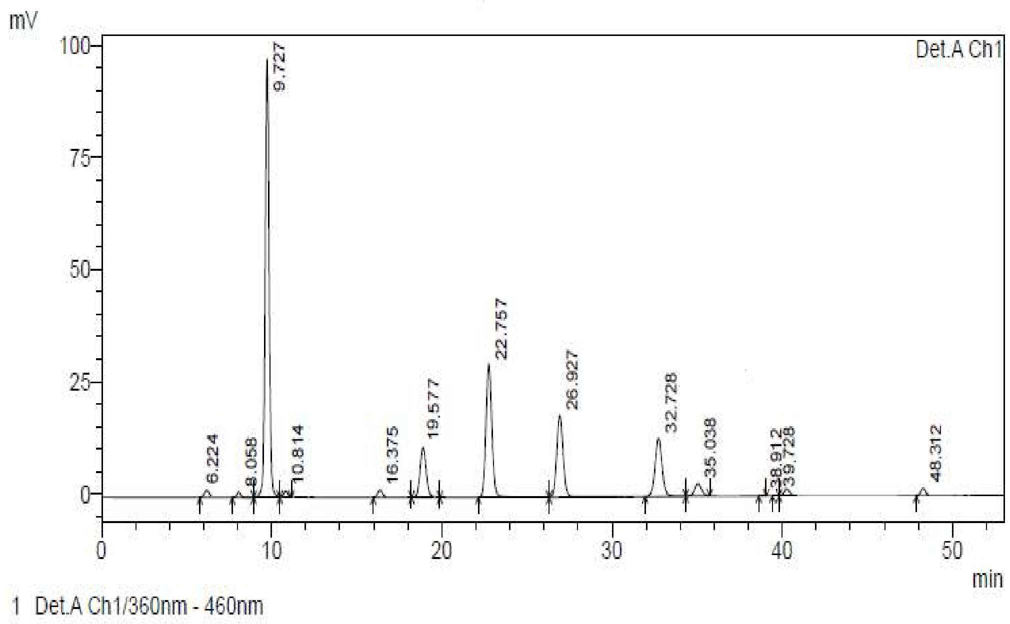

Figure A.2 300 ppb stock solution of PAHs chromatogram

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PUBLICATIONS IN INTERNATIONAL JOURNALS

1) Uzun, A. and Bozkurt, H. (2010). "Changes in headspace flavour component composition and texture of kavurma during cooking process", Fleisch wırtschaft (International Journal for meat production, processing, research), 25, (2), 137-140.

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7) Özcan Uzun, A., Maskan, M., Bedir, M. and Bozkurt, H. (2018). "An Investigation of Increase the Effectiveness of Ohmic Cooking of Meat by Using with Ultrasound Treatment", ICENS, 2-6 May, Kiev, Ukraine.

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