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Effect of hybrid cooking (ultrasound – ohmic – infrared) method on textural and microbial properties of beefs

Auswirkung einer hybriden Garmethode (Ultraschall – Ohmsch – Infrarot) auf die texturellen und mikrobiellen Eigenschaften von Rindfleisch

Anıl Uzun Özcan[1]), Medeni Maskan[2]), Metin Bedir[3]), Hüseyin Bozkurt[2])

Summary

Effects of hybrid cooking (ultrasound – ohmic – infrared) and ohmic cooking alone on textural and microbial properties of beef were investigated to get safer and high quality cooked beef. In hybrid cooking, the beef samples pre-treated with ultrasound for 10, 20 and 30 minutes were cooked ohmically at 40, 55 and 70 Volt for 7 minutes, finally infrared cooking was applied to each side of beef at 3 different temperatures (163, 191 and 218 °C) for 3 minutes. Texture profile of beef muscle (hardness, springiness, cohesiveness, gumminess, chewiness, and resilience) was followed during the processing of hybrid and ohmic cooking alone. At hybrid cooking, voltage increment had a significant effect ($p<0.05$) on hardness, chewiness and gumminess values. On the other hand, generally springiness, cohesiveness and resilience values were not affected significantly ($p>0.05$) by voltage gradient. After ohmic cooking alone, total aerobic mesophilic bacteria (TAMB) count significantly decreased ($p<0.05$) from 5.73 to 4.02 log cfu/g, while total coliform (TC) count decreased from 5.01 to below detection limit by increasing voltage level. However, hybrid cooking process was successful for killing of microorganisms as TC and TAMB counts mainly reached well below detection limits. In this study, hybrid cooking can be considered to be more efficient over ohmic cooking alone since it gave synergistic effects with respect to textural properties and provide best microbiological safety and quality of beef.

Keywords: ultrasound, ohmic, infrared, beef cooking, textural properties, microbial properties

Introduction

Meat is generally cooked before consumption with the exception of prepared raw in certain preparations (steak tartare), specially dried and fermented products. Cooking of meat gets some advantages such as acquiring more palatable and tender meat; This makes the meat more digestable and also more safer since harmful bacteria, parasites etc. are killed (Ranken, 2000; Suleman et al., 2020). The quality of meat is primarily affected by the cooking method (Bejerholm and Aaslyng, 2004). 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, 2017). Because, conventional treatments are relatively inefficient comparing to new technologies in terms of energy requirements, waste recycling, and environmental sustainability (Pratap-Sing et al., 2021). Applications of new and innovative technologies and resulting effects to meat products either individually or in combination are of great interest for meat processing (Cummins and Lyng, 2017). 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. 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 microorganism contamination arises, while interior animal tissue is considered to be sterile. Time and temperature are the important parameters which demonstrate the microbial destruction effectivity. Thermal process designation is very important for meat and meat products to eliminate food-borne pathogens and to reduce the types of degradation. Because microorganisms can grow in fresh meat, the ingredients used in meat preparation, and also meat products (Sun, 2006).

A great number of techniques have been used to cook meat; however, the variety in cooking duration, energy consumption and meat palatability may vary with each technique. During the cooking process, some techniques did not provide homogeneous heat distribution, while some techniques require high temperatures, long times or high cost (Pathare and Roskilly, 2016). But, it would be good to have an economic and simple alternative cooking method suitable for both catering sector and industrial use. Ohmic cooking method is one of the alternative cooking methods. Ohmic cooking is an emerging thermal processing technology and describes the process when an electrical current is passed directly through a food and the resistance against electric current by food leads to generation of heat within product (Zell et al., 2009). Ohmic cooking, generates heat, by direct energy application, in a volumetric fashion which reduces the long cooking times associated with conventional methods (Lyng et al., 2010). Ohmic cooking potentially offers safety for faster and instant cooking of meat products (Indiarto and Rezaharsamto, 2020). However, meat samples commonly have heterogeneous structures because of their fat content which affects the uniform distribution of heat (Yıldız-Turp et al., 2013). It is anticipated that ohmic cooking method is not sufficient to be carried out alone especially without brown color. Also, ohmic cooking alone is not an effective method for developing many quality parameters. It should be combined with another alternative methods that are economic, easy to apply and do not have negative effects on the safety and quality of the meat. For this reason, ultrasound pre-treatment before ohmic cooking and infrared cooking application after ohmic cooking are being considered to be effective in terms of practical usage, safe product, shorter process time, providing homogeneous structure, desired crust layer and tender structure in beef meat (Özcan Uzun, 2018). To the best of our knowledge, in the literature, there is not more information about the details of combination of these three methods for cooking of meat. Therefore, it was aimed to investigate the effect of ohmic cooking alone and the consecutive application of ultrasound-ohmic-infrared cooking methods on textural and microbial properties which are very important indicators for the quality and safety of beef and in this study it is important to find an alternative method, ohmic cooking, that met all of these requirements to determine voltage degree, thickness of beef and duration of the process. Thus, finding an alternative cooking method that can cook meat better by combining ohmic cooking with other methods such as using ultrasound, ohmic and infrared treatments was main goal of this study.

Materials and methods

Meat sample

Beef *(Longissumus dorsi)* loin from single three years old cattle was obtained from a local supermarket in Gaziantep, Turkey. The meat was frozen at –70 °C until used for cooking. The required meat samples were removed from the freezer and allowed to thaw for one day at 4 °C.

Ultrasound pre-treatment

Ultrasound pre-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. Two replicates were performed for each level (Özcan Uzun, 2018).

Ohmic cooking procedure and electrode designation

For the designation of ohmic cooker, a 5 kw conductor, a 220 Volt input – 24 Volt output AC power supply, a limit switch, a 10 A fuse, a voltmeter and an ampermeter were used. A cylindrical test cell with the dimensions of 5 cm length and 3.5 cm diameter was designed with open edges in order to place the sample. Then, electrodes with 3.5 cm diameter that contacts and covers the meat surface completely were needed. Stainless steel electrodes (430 type) were tested and cooking was very successful. For this system, meat was cut by a 5 cm diameter sharp cutter and then placed into the test cell. Next, 430 type stainless steel electrodes were placed into the open gaps at the edges of the test cell to completely cover and be in contact with the meat sample surface. Homogeneous and uniform cooking of meat was achieved. 40, 55 and 70 Volt levels were used and application time was adjusted to 7 minutes for ohmic cooking. Two replicates were performed for each level (Özcan Uzun et al., 2018).

Infrared cooking procedure

Infrared cooking was performed with Frigidaire Professional Stainless Programmable 6 Slice Infrared Convection Oven (Frigidaire, FPCO06D7MS 120V-60 Hz 1500 Toaster Oven, US). In infrared cooking, three different temperature settings were used. These were 163°C (325 °F), 191 °C (375 °F) and 218 °C (425 °F) as oven temperature. In order to get the temperature in the center of meat sample as 72 °C, time of infrared cooking was set to 3 minutes for each side of meat sample. Two replicates had been used for each treatment at every level (Özcan Uzun et al., 2018)

Flow diagram

Flow diagram of hybrid and ohmic alone cooking systems are given in Figure 1 and Figure 2, respectively. Experimental set-up of hybrid cooker is given in Figure 2.

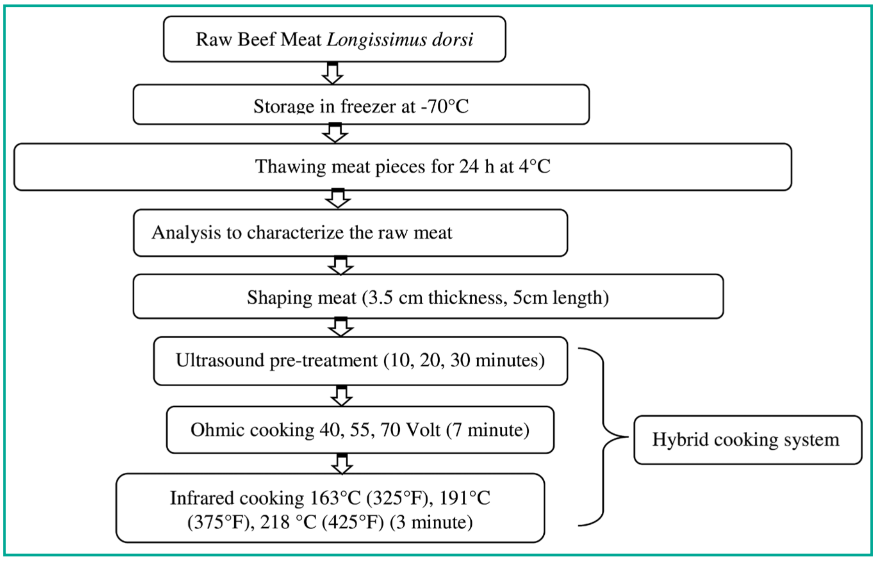

FIGURE 1: *Flow diagram of hybrid cooking system (Özcan Uzun, 2018).*

Texture analysis

Texture profile analysis (TPA) was performed using a TA.XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY/Stable Microsystems, Godalming, UK) to determine hardness (N), springiness, cohesiveness, gumminess, chewiness (N) and resilience. Test conditions were: aluminum 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 was performed at room temperature (20 °C ±2). The analyses were performed in two replicates (Özcan Uzun, 2018).

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 TAMB count, nutrient agar (Sisco Research Laboratories, India) and for TC count VRBL (violet red bile with lactose, Conda Laboratorios, Spain) agar was used. A 25 g of sample was removed from each beef and homogenized in a sterile Waring blender containing 225 ml 0.1% peptone water. Dilutions were prepared from 10^{-1} to 10^{-6} for each sample. A 0.2 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 h to 72 h. 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 logarithm of total number per g (log cfu/g) of meat sample. The analyses were performed in two replicates (Özcan Uzun, 2018).

Statistical analyses

ANOVA was performed for texture profile values (hardness (N), springiness, cohesiveness, gumminess, chewiness (N), resilience) and TAMB and TC counts as a function of voltage value for ohmic cooking alone and ultrasound time, voltage level and infrared cooking temperature for the hybrid cooking. SPSS version 21.0 was used to evaluate the significant differences at $p<0.05$ level among the samples. For identification of homogeneous groups of cooking methods variables, Duncan's multiple range test was applied. Trends were considered as significant when the means of compared parameters differed at $p<0.05$ level.

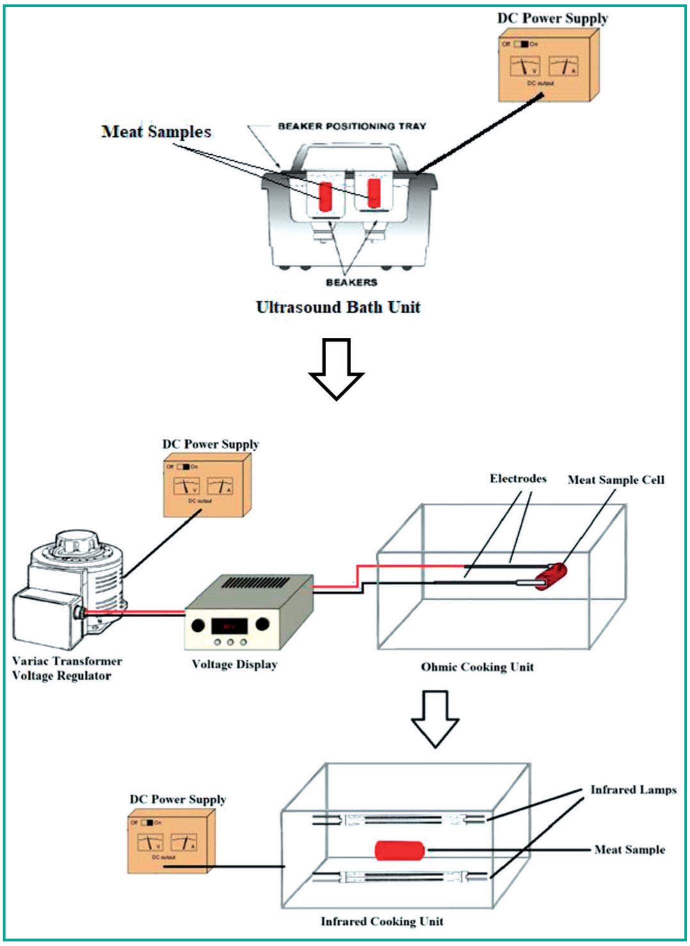

FIGURE 2: *Experimental set-up of hybrid cooking systems (Özcan Uzun, 2018).*

Results and discussion

Texture

At ohmic cooking alone process, the textural behaviours of cooked beef samples were significantly different from ($p<0.05$) raw material (Figure 3a – 3e). 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. These results are in agreement with our findings. Hardness and chewiness value of ohmic cooked beef samples firstly increased then decreased by increasing voltage gradient (Figure 3a–3e). The increase in hardness can be explained by coagulation of protein (myosin) in meat caused squeezing of water around the groups of myosin. 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. By increasing voltage gradient more, hardness and chewiness values decreased (Figure 3a – 3e). This could be due to change of collagen into soft gelatin and meat released it tight texture (Huidobro et al., 2005; Uzun, 2010). Also, Gavahian et al. (2019) stated that, heating food materials volumetrically and at a higher rate than the conventional process can affect the kinetic of textural softening and the product texture. Gumminess values increased significantly ($p<0.05$) by the increase of voltage gradient. Springiness values varied between 0.632 and 0.723 while cohesiveness ranged between 0.628 and 0.748 during the ohmic processing. İçier et al. (2010) studied effect of 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 improving juiciness compared to other heating technologies.

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 and chewiness values of some of the samples (Figure 3a – 3e). On the other hand springiness, cohesiveness and resilience values of many of samples were not affected significantly ($p>0.05$) by changing voltage gradient according to one way ANOVA results. The highest hardness and chewi-

FIGURE 3: *(a), (b) and (c) represents hardness values of ohmic and hybrid cooked beef (ultrasound – ohmic – infrared) samples, (d), (e) and (f) represents chewiness values of ohmic and hybrid cooked beef (ultrasound – ohmic – infrared) samples. Different capital letters indicate means are significantly different in the samples at $p<0.05$ level for ohmic cooking at three different voltage (40, 55 and 70 V) level. Different small letters indicate means are significantly different in the samples at $p<0.05$ level for the same ultrasound time and infrared temperature of hybrid cooking. In Figures 3(a), 3(b), 3(c), 3(d) and 3(e); 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.*

ness values were generally obtained at 70 V values of hybrid cooked samples. These were cooked at 10 min. ultrasound – 70 V ohmic – 163 °C (325 °F) infrared, 20 min. ultrasound – 70 V ohmic – 218 °C (425 °F) infrared and 30 min. – 70 V – 191 °C (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.

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 did not affect the texture of the hamburger meat. Lyng et al. (2010) indicated a similar level of tenderness amongst the combined ohmic/convection and convection alone. Zhou et al. (2012) also studied the effects of characteristic changes of collagen on meat physicochemical properties of beef during ultrasonic processing and they indicated that ultrasound treatment had significant effects on hardness, springiness, cohesiveness, gumminess and chewiness values.

In this study, ultrasound, ohmic and infrared interaction namely hybrid cooking caused a significant effect ($p<0.05$) on hardness, gumminess and resilience of beef muscle, however, on springiness, cohesiveness and chewiness values it did not cause a significant effect ($p<0.05$).

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

Before 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 from the Figure 4a., TAMB count significantly decreased ($p<0.05$) to 4.02 log cfu/g, TC count decreased significantly ($p<0.05$) to well below the detection limit by increasing voltage level. Makroo et al. (2020) indicated that voltage gradient has a direct relationship with the reduction of microorganism. İçier et al. (2010) 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 (Içier et al., 2014). They observed that voltage gradient and voltage gradient-holding time were 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 is close to our results. They investigated that, the observed reduction was limited in terms of microbiological safety, it is tolerable for semi-cooked meat balls, which will be further processed by another thermal method. Another challenge study was carried out by Zell et al. (2009). They found that whole beef cooked rapidly by ohmic heating (7 fold time reduction) gave comparable quality level to those achieved by conventional methods while also reducing cook losses. According to Global Agricultural Information Network (GAIN) report of "Microbiological Standards for Meat and Meat Products", microbial load limit for cooked or semicooked meat samples must not be higher than 10^4 cfu/g (4 log cfu/g) for TAMB count (GAIN, 2015). 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 reached well below the detection limit. Accordingly, it was revealed that ohmic cooking is an effective method for reduction of microbial load of meat sample. In ohmic cooking, when electric current passes through a conductor the movement of charges within the material results in excitation of molecules (or atoms) in the path to be excited, resulting in an increase in 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. 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 electrical conductivity and voltage gradient. In ohmic cooking, the food acts as a resistor. The dissipation of electrical energy causes heating of the substance and therefore also the heat is generated inside the food causes microbial reduction. However, ohmic cooking alone is not adequate lonely for reaching well below the detection limits in terms of microbial load of beef samples. Ultrasound-ohmic-infrared cooking application in other words hybrid cooking process is also successful for reaching well below the detection limits. TAMB and TC counts in raw beef were found to be 5.29 and 1.70 log cfu/g, respectively. TC count reached below detection limits in all samples at the end of cooking process. TAMB count also reached below detection limits in most samples except 10 min. ultrasound – 40 Volt ohmic – 163 °C (325 °F) infrared (2.90 log cfu/g), 10 min. ultrasound – 55 Volt ohmic – 163 °C (325 °F) infrared (1.84 log cfu/g), 10 min. ultrasound – 40 Volt ohmic – 191 °C (375 °F) infrared (1.77 log cfu/g) cooked beef samples (Figure 4a). This indicated that in the hybrid cooking system, microbiological safe levels indicated by GAIN had already been reached (GAIN, 2015). However, when working with 10 minute ultrasound time and 163

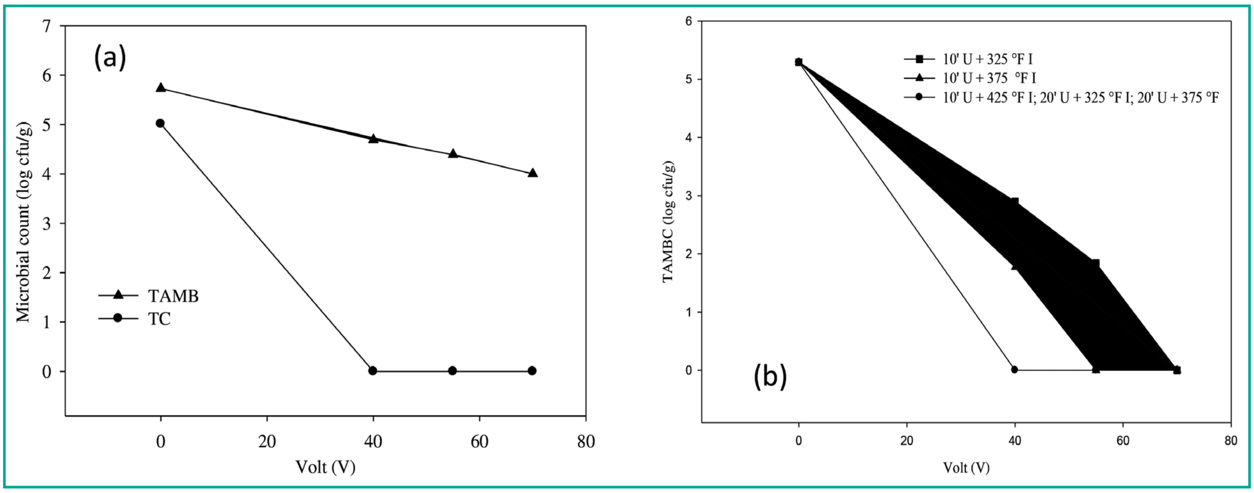

FIGURE 4: *(a) TAMB and TC counts of ohmically alone; (b) TAMB counts of hybrid (ultrasound – ohmic – infrared) cooked meat. Abbreviations: ,: minute; U: Ultrasound; °F: Fahrenheit Degree; I: Infrared.*

°C (325 °F) infrared temperature, 70 voltage level should be used to reach well below the detection limits. On the other hand, when working with 10 min ultrasound time and 191 °C (375 °F) infrared temperature, voltage level should be higher than 40 V to get well below the detection limits of microorganisms. The rest of the interactions of hybrid cooking system were already safe in terms of microbiological quality of beef muscle and also total viable counts were destroyed predominantly in these interactions.

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 reach well below the detection limits in beef muscles from the stand point of best microbiological quality. In this way, hybrid system which is the consecutive application of ultrasound, ohmic and infrared treatments was better to provide best microbiological safety and quality exactly while cooking process of beef muscles compared to ohmic cooking alone process. Ensuring safety of beef muscle from the microbiological point of view is very significant. At this point, cooking system gains importance.

Conclusions

As a conclusion, ohmic cooking alone provided better textural properties and reduced microbial levels in cooked beef meat by increasing voltage level compared to raw beef. Ohmic cooking appears to be an effective method for reducing the microbial load and providing textural quality but it was not an adequate method by itself. Hybrid cooking system involves three different treatments which seems more challenging than using a single method but in this study it was seen that ohmic cooking efficiency increased with the support of ultrasound and infrared treatment. In hybrid cooking sytem, well below the detection limits of beef samples in terms of microbial load were obtained and more harder and chewier beef samples were also obtained at higher voltage levels with comparing to ohmic cooking alone process. By this way, with the reinforcement of ultrasound and infrared treatment to ohmic process, hybrid system formed a synergistic cooking effect.

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Conflicts of interest

The authors declare no conflict of interest.

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