Microwave Processing of Meat

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1. Introduction

In recent years, the rapid growth of chilled and frozen food market is due to rapid reheating instruments such as domestic or commercial microwave oven as well as conventional ovens. The goal of these products manufacturers is to cook the products to a temperature that would ensure the reduction of pathogenic bacteria to a safe level. It is a common way to heat the chilled foods in a microwave oven to a minimum temperature of 70°C for at least 2 minutes or an equivalent temperature/time condition, e.g. 75 °C for 30 seconds, 65 °C for 10 minutes, etc. A small change in heating time in a microwave oven has a large effect on the survival of Salmonella spp. In inoculated meat loaves, Salmonella survived after 3.5 minutes heating but it was not found when the heating time was increased to 4 minutes (European Chilled Food Federation, 1996; Farber et al., 1998; Levre & Valentini, 1998).

The ever-increasing range of processed foods is produced with microwave reheating instructions surround the world as well as increased microwave applications. In industrial applications, the microwave systems have been developed for drying, pre-cooking of bacon/meat, pasteurization of ready meals and the tempering of meat and fish. There is, however, a growing new application such as blanching, baking and microwave phyto-extraction. Microwave heating was primly applied in agriculture, in grain drying and insect control. In addition, it was used for food drying, blanching, pasteurization and cooking (Chen et al., 1971; Lin & Li, 1971; Maurer et al., 1971; Bhartia et al., 1973; Nelson, 1973; Jaynes, 1975; Avisse & Varaquaux, 1977; Nykvist & Decareau, 1976; Sobiech, 1980; Shivhare et al., 1994; Tulasidas et al., 1995; Begum & Brewer, 2001; Hong et al., 2001; Sumnu, 2001; Ramesh et al., 2002; Beaudry et al., 2003; Severini et al., 2004; Williams et al., 2004; Zhang et al., 2004).

Frozen materials are usually thawed or tempered before further processing in food industry. Thawing is usually regarded as complete when all the material has reached 0 °C and no free ice is present. This is the minimum temperature at which the meat can be boned or other products cut or separated by hand. Lower temperatures (e.g. -5 to -2 °C) are acceptable for mechanical chopping of product, but such material is `tempered' rather than thawed. The two mentioned processes are not same with together because tempering only constitutes the initial phase of a complete thawing process while thawing is often considered as simply the reversal of the freezing process. However, inherent in thawing is a major problem that it does not occur in freezing operation. Thawing operation has some steps, at first the surface areas of food to rise in temperature and bacterial multiplication can restart. On large objects surface spoilage can occur before the centre regions have fully thawed. It is interesting to know that, there is basic difference between conventional thawing and tempering systems with microwave. Conventional thawing and tempering systems supply heat to the surface and then rely on conduction to transfer that heat into the centre of product but microwave systems use electromagnetic radiation to generate heat within the food. The main detrimental effect of freezing and thawing on meat is the large increasing in amount of proteinaceous fluid (drip) released on final cutting. Several studies showed that fast thawing rates would increase amount of drip. Microwave thawing has some advantages: in this way, the ice formation during freezing breaks up cell structure and fluids are reduced during thawing but microwave thawing has a better quality product than thawing at 4 or 21 °C. It is necessary to more investigate the microwave processing because of large applications of microwave in meat processing (tempering, thawing and cooking) as well as quality control of meat and meat products (Riihonen & Linko, 1990).

2. Definition

High-frequency heating is considered a thermal process which causes oscillation of water molecules, friction, and resultant heat generation. In several studies it was permitted the radiofrequency heating include 13.56, 27.12, and for microwave applications is 40.68 MHz and 433, 915, 2450, and 5800 MHz. Radiation is a mechanism for heating meat by electromagnetic energy. When the electrons in atom move from a higher to a lower energy state, it sends energy as waves. These waves are not in the same energy level and frequencies. Lower energy electro-magnetic radiation (microwave, radio, TV) occurs as very long waves with frequencies ranging from 300MHz to 300 GHz. Unlike gamma and X-rays, non-ionizing MW energy is sufficient to move the atoms of a molecule, but can not change its chemical bounds. Also MW move at the same speed as light waves essentially. Metallic objects reflect them; some dielectric materials absorb them while others transmit them. Water, carbon, and foods which are high in water are good MW absorbers, while thermoplastics, glass and ceramics allow them to pass through and they can not absorb it completely. When the polar molecules such as H_2O place in a magnetic field, they line up with the field. If the field alternates, the polar molecules alternate at the MW frequency to maintain this alignment. As they rotate, they disrupt H-bonds between adjacent water molecules, generating heat. Freedom of the polar molecules plays an important role in the rate of heat generation. Because the movement of water molecules in ice is restricted, it is a poor MW energy absorber. In an electric field kinetic energy accelerates the ions in solution (Na^+, Cl^- and Ca^{++}). They crash with other ions and give up heat. The more ions in solution, the higher the kinetic energy release (Decareau and Peterson, 1986; Hugas et al. 2002; Aymerich et al. 2008).

All microwave ovens have a similar design that includes a magnetron device as a power source and a waveguide to bring radiation to a heating chamber. A radiofrequency oven which is known as RF applicator is equipped with a generator coupled with a pair of electrodes. Microwaves can penetrate to a depth of 5 to 7 cm, which results in faster cooking and fewer nutrient changes compared with conventional ovens. It was showed 2 $\log_{10}$ CFU/g reductions in total microbial flora after microwaving meat balls at 2450 MHz frequency, in an 800 W oven, for 300 seconds. Conveyor zed systems have been applied to thawing of meat, in some cases using water surrounding the material to aid temperature

uniformity. Electromagnetic (900-3000 MHz) waves are directed at the product through waveguides without electrodes. Potentially very rapid, the application is limited by thermal instability and penetration depth. Instability results from preferential absorption of energy by warmer sections and by different ingredients, such as fat. Warmer sections may be present at the start of the process; for example, the surface temperature may be warmer than the middle, or they may be produced during the process. In the extreme, such warming can lead to some parts of the food being cooked while others remain frozen. In addition to these problems, the high capital costs of equipments have greatly limited commercial applications. Attempts to avoid runaway heating have involved low-power (and hence longer duration) microwaving, cycling of power on and off to allow equalization periods, and cooling of surfaces with air or liquid nitrogen. Penetration depth depends upon temperature and frequency, being generally much greater at frozen temperatures and greater at lower frequencies (Murano 2003; Yilmaz et al. 2005; James & James, 2010).
As mentioned before, microwaves include waves with wavelengths from 3mm to 3m. In the electromagnetic spectrum, microwaves are located between radio waves at low frequencies and infrared at higher frequencies (Fig. 1). In addition to industrial applications of microwaves in meat tempering, thawing and cooking, microwave was used to detect the fraudulent addition of water in meat products. By using microwave, a nondestructive method was developed for measuring fat in fish and meat, measuring water activity in protein gels and also sensory controlling meat and fish freshness based on the change in dielectric properties (Kent et al. 1993; 2000, 2001 & 2002; Kent 1990; Boggaard et al. 2003; Clerjon et al. 2003; Tejada et al. 2007; Clerjon & Damez 2007).

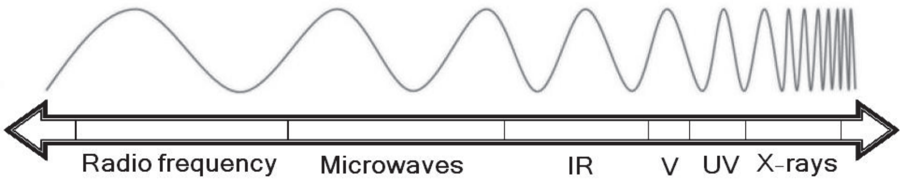

Fig. 1. The electromagnetic spectrum.

2.1 Dielectric properties of foods

Microwave with 915MHz frequencies, is used for industrial heating, and 2450 MHz, in domestic microwave ovens worldwide. Ice, having a very small loss factor, is almost transparent to microwaves. Oils are esters of long-chain fatty acids which have much less mobility compared to water molecules in response to oscillating electromagnetic fields. The dielectric constant and loss factor of oil are therefore very small compared to free water. The air voids in some foods reduce the loss factor and increase the penetration depth of microwaves at 915MHz and 2450 MHz. Variation in dielectric properties among high protein products can be as large as among other groups of food at 915 MHz and 2450 MHz. Temperature and salt are important factors on dielectric properties of meat products such as cooked ham and beef. The loss factor of cooked ham is much larger than cooked beef. The penetration depth of microwaves at 915MHz and 2450 MHz in ham is less than 0.5 cm. The dielectric constants and penetration depth of microwaves in these foods decrease, while the loss factors increase, along with increase in temperatures at 915 MHz and 1800 MHz. In general, predicting the dielectric properties of complex food products is difficult and its direct measurement needs to be made over specific composition, temperature and frequency ranges (Wang et al., 2003; Guan et al., 2004).

2.2 Water migration adjustment as temperature controller

Adjusting the meat composition in a microwave burger/bun combination can offer flexibility to temperature during microwave heating. It is important to adjust the food with emulsifiers, gums, proteins, and sugars to manage the water content of the meat and the bun separately so that, when processed together in a microwave environment, the bun does not burn while the meat is cooking. With the addition of vegetable fiber, there is swelling of the fiber and fat absorption which interacts with the beef protein to form a complex matrix preventing fat and moisture release (Anderson & Berry, 2001; Lyng et al., 2002; Parker & Vollmer, 2004).

2.3 Microwave interactions with food components

Variations in electric fields, food constituents and the location of the food in a MW oven can lead to no uniform heating, allowing for less-than-ideal interaction of food components and survival of microorganisms. A number of techniques to improve uniformity of MW heating, such as rotating and oscillating foods, providing an absorbing medium (water) around the product, cycling the power (pulsed power), and varying the frequency and phase, can improve the situation; however, dielectric properties of the food must be known in order to develop effective processes (Yang & Gunasekaran, 2001; Guan et al., 2004).

3. Commercial microwave systems

A wide range of batch and continuous commercial microwave systems for thawing and tempering have been produced since the 1970s and now microwave drying and cooking are used for food processing. The systems were applied to temper meat, fish, butter and berries. A number of the batch systems were used either as one stage of a hybrid microwave/conduction system or to augment large conduction systems by fast tempering of small batches of urgently required material. Industrial systems can be batch or continuous and range in size from small systems that can process one block (25 kg) of food to large continuous tunnels processing up to 8 tones per hour. A single 25 kg block of frozen meat can be tempered in 65 s. the throughput is very dependent on product composition and the final temperature achieved after tempering. The systems are fabricated out of stainless steel for food applications with a uniform load distribution within the oven; a multi-mode cavity applicator develops a uniform heat distribution in the entire oven. The belt material and configuration are selected based on the nature of the product being heated. Each end of the conveyor is provided with a special vestibule to suppress any microwave energy leakage into the environment. To assure uniform heat distribution in a large variety of load configurations, each oven section is provided with a waveguide splitter with dual microwave feed points and mode stirrers (Swain & James, 2005).

4. Application of microwave heating for meat processing

4.1 Microwave tempering

Tempering of frozen food, can make food easier to slice and reduce drip loss. Frozen meat is heated to just below the freezing point (-2 to -4 °C) can be tempered by MW energy in tempering process then allowed to thaw fully at refrigeration temperature. At temperatures slightly below 0 °C, the outer layer of the meat can absorb significant amounts of energy, resulting in overheating near the surface. Frozen foods thawed in the MW may experience `runaway heating' due to selective heating of the liquid phase (opposed to the crystalline phase of the ice). MW power penetration is greater at 915MHz than at 2450MHz so it is more suitable for heating thick masses of materials. Tempering frozen food has been more successful at 915MHz than at 2450MHz, partly because of surface overheating at the latter frequency. This can be balanced, to some degree, by circulating cold air around the product; however, this may increase drip losses by up to 10%. MW tempering requires less time and space, produces little or no weight loss, increases juice retention, and reduces bacterial growth (Decareau & Peterson, 1986; Rosenberg & Boe, 1987).

There are widespread applications of industrial microwave systems for tempering meat. The blocks processed directly from frozen storage can be acceptably tempered in a batch microwave unit to a mean temperature of approximately -3 °C (range -5 to 0 °C) with no hot spots. In general, microwave tempering of blocks for 8 h in ambient temperatures is unsatisfactory. If it is not possible to produce a uniform power/time combination, surface temperatures, especially at the corners of the meat blocks, rose to unacceptable levels and there was substantial drip loss from thawed surfaces. Trials have to be carried out to determine the correct power and time setting for each type of block in optimal tempering. Blocks sorted into batches of similar type should be processed directly from frozen storage under the predetermined conditions. Successful tempering can be made in some minutes using a microwave system, compared with the 1 to 14 days required in industrial air tempering systems. Continuous conveyorized microwave tempering systems using either a single 60 kW magnetron or two 40 kW magnetrons can temper 2 to 2.5 tones per hour depending upon fat content. In large-throughput operations the continuous microwave tempering plant provides considerable flexibility, in that changes in raw material requirements, for the post-tempering processes, can be accommodated in minutes. Using air tempering systems, at least one day and up to eight days are required to accommodate equivalent changes. Microwave systems bring higher product yield due to reductions in evaporative and drip loss during tempering. Since the majority of conventional plants temper material in a wrapped form, evaporative losses are insignificant, while substantial periods at air temperatures above 0 °C would be required before thawing of surface tissues occurred and drip became apparent (Swain & James, 2005).

4.2 Microwave thawing

Microwave thawing utilizes electromagnetic waves directed at the product through waveguides without using electrodes. Whilst the thawing of frozen food by microwave energy is a very fast method, its application is limited by thermal instability. In microwave heating, parts of the food may be cooked whilst the rest remains frozen. The absorption of electromagnetic radiation by frozen food can increase the temperature, especially at -5 °C. During irradiation, if a region of the material is slightly hotter than its surroundings, proportionately more energy will be absorbed. Enthalpy increasing cause the absorption to increases and the unevenness of heating worsens at an ever-increasing rate. If irradiation is continued after reaching the hot spot to its initial freezing point, the temperature rises at appalling rate. Lowering the power density to allow thermal conduction to even out the enthalpy distribution through the food can reduce such runaway heating. Since the main instability tends to occur at the surface, attempts have been made to cool the surface during thawing using air or liquid nitrogen. A hybrid microwave/vacuum thawing system was developed in the 1980s in which boiling of surface water at low temperature was used to cool the surface. The system consisted of a cylindrical vacuum chamber approximately 1 meter in diameter and 1 meter long. The chamber could be evacuated to absolute pressures as low as 10 mbar by a water ring pump in series with a rotary pump. Microwaves at a frequency of 915 MHz were introduced into the chamber via two waveguides positioned near the top at the front and rear of the plant. The microwaves were produced by a 25kW generator, though power had to be limited to 2.5kW to avoid arcing problems in the chamber. A large circular twisted disc was rotated within the chamber during thawing to produce a more even microwave field. After thawing, the average meat temperature was 9.4 °C (ranging from -1 to 23.3 °C between blocks) and the maximum surface temperature measured on any block was 28.4 °C. Weight losses averaged 7.6%, which appeared large, but weight loss in commercial systems was stated to range from 2 to 10%. The overall energy efficiency of the plant was 49% with 24% of the energy being absorbed by the structure of the chamber. The combination of microwave energy and cold air with different ambient temperatures can reduce thawing time and avoid runaway heating during microwave-assisted thawing. The microwave power was cycled on and off using hot and cold points control schemes to a predetermined temperature gradient. When appropriate conditions were used, thawing time was reduced by a factor of seven compared to convective thawing at ambient temperature. The rate of sublimation with low microwave power at the surface resulted low weight losses during the process. The temperatures claimed at the end of thawing processes lasting between 24.5 and 34.25 minutes ranged from -1.1 to -2.0 °C. The shielded region was in fluid communication with the cavity so that thawed material may flow from the cavity into the shielded region. Even if microwave-thawing systems have not been commercially successful but microwave-tempering systems have found successful applications in the meat and dairy industry (Bialod et al., 1978; Virtanen et al. 1997; James, 1984; Yagi & Shibata, 2002; Swain & James, 2005).

4.2.1 Vacuum-heat thawing (VHT)

A vacuum-heat thawing system operates by transferring the heat of condensing steam under vacuum to the frozen product. Theoretically, a condensing vapor in the presence of a minimum amount of a non-condensable gas can achieve a surface film heat transfer coefficient far higher than that achieved in water thawing. The principle of operation is that when steam is generated under vacuum, the vapor temperature will correspond to its equivalent vapor pressure. For example, if the vapor pressure is maintained at 1106 Nm^{-2}, steam will be generated at 15 °C. The steam will condense onto any cooler surface such as a frozen product. The benefits of latent heat transfer cooking without any problems which would occur at atmospheric pressure. Thawing cycles are very rapid with thin materials, enabling high daily throughputs to be achieved. The advantage of a high h-value is increasing less marked as material thickness, and beef quarters or 25 kg meat blocks require thawing times permitting no more than one cycle per day. The cost of largest capacity units (10-12 tones) can restrict its application. The frozen product is continuously tumbled with vacuum tumble thawing systems while steam under vacuum condenses on the exposed surfaces of the food. Very fast thawing is claimed to be obtained with small bulk-frozen individual products. However, delicate products such as fish fillets cannot be thawed in such systems (Swain & James, 2005).

4.2.2 Radio frequency thawing

Heat is produced in the frozen foodstuff during radio frequency thawing because of dielectric losses when a product is subjected to an alternating electric field. A homogeneous regular slab is placed between parallel electrodes in an idealized case of radio frequency heating without any heat exchanging. When an alternating electromotive force (emf) is applied the electrodes thawing and tempering using microwave processing the resulting field in the slab is uniform, so the energy and the resultant temperature rise is identical in all parts of the food. Foodstuffs are not generally in the shape of perfect parallelepipeds; for example, frozen meat consists of at least two components fat and lean. During loading, frozen meats pick up heat from the surroundings, the surface temperature rises and the dielectric system is not presented with the uniform temperature distribution required for even heating. By using a conveyorized system to keep the product moving past the electrodes and/or surrounding the material by water, commercial systems have been produced for blocks of oily fish and white fish. Successful thawing of 13 cm thick meat, and 14 cm thick offal, blocks has also been reported but the temperature range at the end of thawing (44 minutes) was stated to be -2 °C to 19 °C and -2 °C to 4 °C respectively, and the product may not have been fully thawed. To overcome runaway heating with slabs of frozen pork bellies, workers have tried coating the electrodes with lard, placing the bellies in oil, water and saline baths and wrapping the meat in cheesecloth soaked in saline solution. Only the last treatment was successful but even that was not deemed practical. An industrial system was installed to thaw frozen blocks of boned-out poultry in the late 1980s. The continuous plant had a throughput of 450 kg per hour with four 12.5kW generators operating at a frequency of 27.12 MHz providing the heating. It was claimed that the process reduced thawing time from 3 to 4 days to less than 2 hours and cut weight loss from 7 to 0.5% (Satchell and Doty, 1951; Jason & Sanders, 1962; Sanders, 1966; Swain & James, 2005).

4.3 Microwave cooking

Microwave or radio frequency cooking are newer methods that have been introduced to the meat industry. Roasts cooked by microwave took less time to reach endpoint temperatures in comparison with conventional methods. Meat cooked with microwaves does not have typical browned surface associated with other methods of cooking because of short cooking time. Radio frequency as a volumetric form of heating is another rapid cooking alternative in which heat is generated within the product, which reduces cooking times and could potentially lead to a more uniform heating. Microwave oven cooking tends to retain higher amounts of vitamins such as retinol, thiamin, and riboflavin compared with earth-oven-cooked meat. The difference in vitamin retention could be due to a higher cooking temperature of earth-oven cooking compared with microwave cooking (Welke et al., 1986; Kumar & Aalbersberg, 2006; Zhang et al. 2006).

In cooking process, the contractile proteins of meat (myosin and actin) will denature and the connective tissue (collagen) under goes to solubilize. MW heating can solubilize more collagen (percentage of hydroxyproline) than does boiling. In general, MW-cooked meat and poultry have higher cooking losses than those cooked by conventional methods (Moody et al., 1978; Riffero & Holmes, 1983; Yarmand & Homayouni, 2009); however, species (beef, pork, and poultry) and cut have important role in losses and palatability. Cooking losses, evaporation and drip losses were greater for steaks cooked in MW convection ovens compared with those cooked in forced air convection or conventional ovens, though they found no difference in juiciness, tenderness, beef flavor, or external color of the steaks.

Evaporative losses were higher for oven dry-roasted beef than for MW- convection roasts, which were higher than MW roasted samples. Drip losses were highest for MW, followed by oven roasted, then by MW-convection roasted samples. Although Instron shear values did not differ, oven dry-roasted samples were judged as tender by taste panelists. Lean meat cook yield was lower for MW-cooked rib eye roasts while it was the same for round and chuck roasts, whether cooked conventionally or in the MW. Tenderness, softness, natural flavor and tenderness (shear force) were unaffected. MW-cooked rib eye roasts were browner and less juicy. Visual color and tenderness improved for meat products cooked in the MW oven. There were no differences in drip loss of MW-cooked chops, though evaporative and total losses were lower than for broiling. Flavor scores were highest for broiled chops and did not differ due to MW power level. Chops cooked at low MW power were juiciest and tenderness varied inversely with cooking rate. Overall acceptability was lowest for chops cooked at high MW power level. Textural analysis showed greater peak forces for hot air oven-cooked products compared to MW-cooked products. MW cooking time was shorter and produced more uniform heating, though flavor was better in hot air oven-cooked products. Cooking time of chicken breasts increase with decreasing power level, but cooking losses are not affected. Both sensory and instrumental tenderness (Instron compression) were best at 60% power level, while juiciness, mealiness and flavor were unaffected by power level. It was reported that convection-MW-cooked chicken was more tender, juicy and acceptable than MW-cooked chicken even if its flavor intensity was similar (Hines et al., 1980; Fulton & Davis, 1983; Payton & Baldwin, 1985; Hammernick-Oltrogge & Prusa, 1987; Howat et al., 1987; Barbeau & Schnepf, 1989; Yarmand & Homayouni, 2009).

Thiamin retention ranged from 77% in conventionally cooked chicken breasts to 98% in MW-cooked chicken legs. Exposure of pre-rigor broiler muscle to MW energy can decrease glycogen metabolism but it has no effect on ATP retention and is not improve tenderness. When meat is cooked in the MW, addition of fluids and other ingredients, and cooking from the frozen state, appear to improve the overall outcome. Curing of buffalo meat using a polyphosphate solution may increase pH from 5.70 to 6.12 and reduce cooking loss from 17.5 to 10.3%. When cooking started from the frozen state, roasts cooked by MW on low power were comparable to those conventionally cooked in sensory quality. Roasts cooked from the frozen state by MW on high power had lower palatability scores (except flavor) and higher shear values. While MW cooking resulted in lower fat contents, and higher water-holding capacity, TBA value and cook yield than conventional oven cooking. Visually, MW-heated beef may appear to be unevenly cooked. MW-thawed and cooked roasts and steaks may be redder in the interior, and lighter and more yellow on the exterior, than their broiled counterparts. The irregular shape of many whole meat cuts results in significantly non-uniform heating. In addition, bone reflects MW, causing overheating in the regions adjacent to the bone (Moody et al., 1978; Dunn & Heath, 1979; Drew et al., 1980; Riffero & Holmes, 1983; Mendiratta et al., 1998; Hoda et al., 2002).

The temperatures experienced by a MW-heated beef slab can vary by as much as 50 °C. This variation is a function of slab thickness (between 1 and 3 cm) and time, or a function of time alone for slabs >4 cm thick. Thermal insulation at the faces of the slab increases this variation. MW is used primarily for reheating precooked meat products, making cook loss even more problematic. Because fluid losses appear to be the primary roadblock in producing precooked, reheatable meat products, adding fluid (enhancement) has been evaluated in an effort to produce a juicy product. Pumping fresh meat to 10% over original weight to produce 1% salt and 0.3% phosphate in the final product can produce an acceptably palatable, value-added,

precooked product (boneless pork roast) designed for MW reheating. However, flavor may suffer during MW reheating. Reheating of precooked frozen turkey in MW and conventional ovens tends to create stale, aldehyde-like aroma. Meaty-brothy flavor and aroma were more intense in MW-reheated meat. MW-reheated light meat was flat or bland flavored, less juicy and higher in moisture content than conventionally reheated meat. MW cooking had no effect on chicken flavor or aroma, though MW reheating resulted in less warmed-over flavor than conventional reheating. TBA analyses showed that multiple reheating of dark turkey meat using MW energy retarded lipid oxidation, including that caused by NaCl (2.0%) which was a pro-oxidant compared to KCl (2.0%). MW reheating did not influence warmed-over aroma or flavor or TBA values of cooked stored roast beef. Development of off-flavors may be somewhat species-specific (Cipra & Bowers, 1971; Hsieh & Baldwin, 1984; Steiner et al., 1985; Boles & Parrish, 1990; King & Bosch, 1990).
Cooking fresh meat in a microwave can represent a challenge since the cool air surrounding the meat results in lack of browning. While the meat heats up inside, there is mass transfer from the interior to the outside, resulting in a tough, dry and flavourless product. Ingredient selection can target these problems, such as a salt-based coating to attract microwave energy to the surface of the meat along with a colouring agent, a water binding ingredient (such as starch) to reduce moisture loss and an enzyme to retain tenderness. Flavours can be added for overall improvements. In general it is recommended to keep the salt concentration as low as possible to improve the penetration depth and slow the heating at the surface while providing more uniform heating and avoiding thermal runaway. On the other hand, the addition of salt may be recommended in some cases as it can increase the heating rate at the surface for particular applications (Schiffmann, 1986; Taki, 1991; Schiffmann, 1997).

5. Microstructure of microwave processed meats

Quality control methods and microstructural evaluation were employed to study the qualitative parameters of meat and meat products. Among these methods, the environmental scanning electron microscopy (ESEM) has its own advantages for evaluation of microstructural changes in meat especially for comparing the effect of various heat treatments (Arvanitoyannis & van Houwelingen-Koukaliaroglou, 2003; Papadima, et al., 1999; Tzouros & Arvanitoyannis, 2001; Yarmand & Homayouni, 2009; 2010).

5.1 Optical microscopy

Microscopical techniques are used to characterize meat structure. Optical microscopy achieved the observation of fat globules distribution and protein gel in emulsion-type buffalo meat sausages. It revealed that caseinate and modified whey form distinct dairy protein gel regions within meat batters, and this could explain their ability to enhance the textural properties of the meat batters compared with the other dairy proteins (Krishnan and Sharma 1990; Barbut, 2006).

5.2 SEM and ESEM

Scanning electron microscopy (SEM) and environmental scanning electron microscopy (ESEM) have been used for the examination of living and fresh botanical samples including fungal mycelium and cross sections of stems from different plant sources. ESEM has been known as one of the most interesting new developments in the field of electron microscopy. A number of studies have demonstrated the use of ESEM for hydrated biological samples.

Some research compared unprocessed ESEM specimens and samples prepared by conventional methods. Much research has been done on the study of wool fiber. Processes for industrial wool commence with sheep breeding and conclude with the study of finished fabric. Investigations in many of these processes can be largely enhanced using ESEM microscopes and techniques. Techniques of ESEM have been demonstrated by Baumgarten (1990) and Peters (1990). In this study ESEM has been applied to study the microstructure of goat semimembranosus muscle, using raw muscle as a control and comparing it to different heat treatments including conventional and microwave heating. Scanning electron microscopy was useful to show structure differences in low-fat sausages. The environmental scanning electron microscopy (ESEM) is capable of examine specimens in a gaseous environmental saturated with water vapor and higher resolution micrographs have been illustrated at the presence of gas. The environmental scanning microscope has been described as a scanning electron microscopy technique to retain a minimum water vapor pressure of at least 609 pa in the chamber specimen. ESEM creates the possibility of testing practically any sample which is wet (Fig. 2). The difference of ESEM from conventional SEM is its capacity to examine materials consisting of liquids and oils in their natural situation without any initial preparation for the samples (Danilatos, 1981; Danilatos & Postle, 1982; Danilatos, 1989; Danilatos, 1991; Klose, et al., 1992; O'Brien, et al., 1992; Wallace, et al., 1992; Uwins, 1994; Morin et al. 2004; Cáceres et al. 2008).

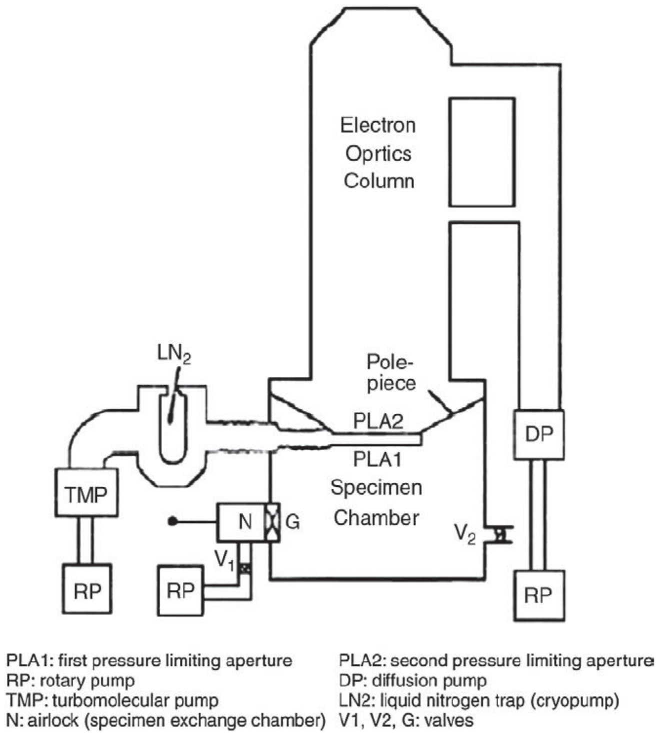

Fig. 2. Diagrammatic representation of a two-stage differential pumping system for an ESEM. Source: (Danilatos, 1991).

The two main parts of the instrument include an electron gun chamber or electron opticsolumn and specimen chamber. The gun chamber is located at the top part of instrument and provides a flow of electrons by heating a tungsten filament, lanthanum hexaboride filament or field emission source. The specimen chamber is capable of working at a very poor vacuum unlike any other types of ESEM which require high vacuum. Therefore this specimen will not dry and ESEM is used to observe specimens in the fresh state. Some important advantages have been shown for the gas around the samples in the specimen chamber. Accumulation of charge on insulating samples can be recognized as a basic advantage for this technique. This phenomenon occurs by ionization of the gases inside the specimen chamber and nowadays much work has been done on it. The gas itself can be employed as a detector in the microscope system which is another advantage for ESEM (Parsons et al., 1974; Moncrieff et al., 1978; Crawford, 1979; DaniJatos, 1983, 1986, 1990; Uwins, 1994).
Study of the microstructure of goat SM muscle was carried out by Environmental Scanning Electron Microscopy (Yarmand & Homayouni, 2009; 2010). The result shows bundles of muscle fiber in raw SM muscle that is parallel to each other (Fig. 3 and Fig. 4).

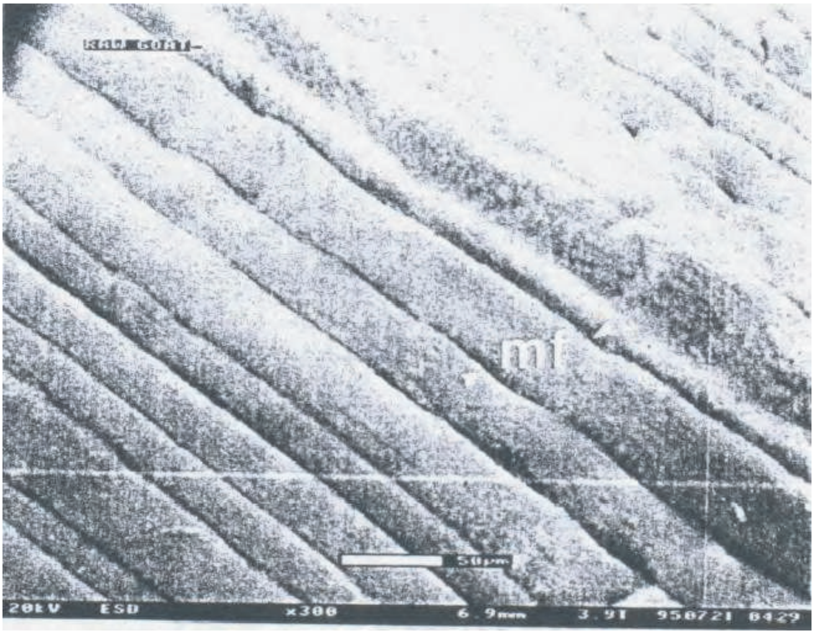

Fig. 3. Illustration of structure of raw goat SM muscle by ESEM (mf: muscle fiber).

The collagen fibers surrounding the muscle fiber are not clear in some Figures, but in Fig. 5 the collagen fibers appear clearer and the myofibril surfaces seem normal. In order to observe collagen more clearly than before, Miller stain was used. This technique increased contrast by increasing the conductivity of the material (Miller, 1971).

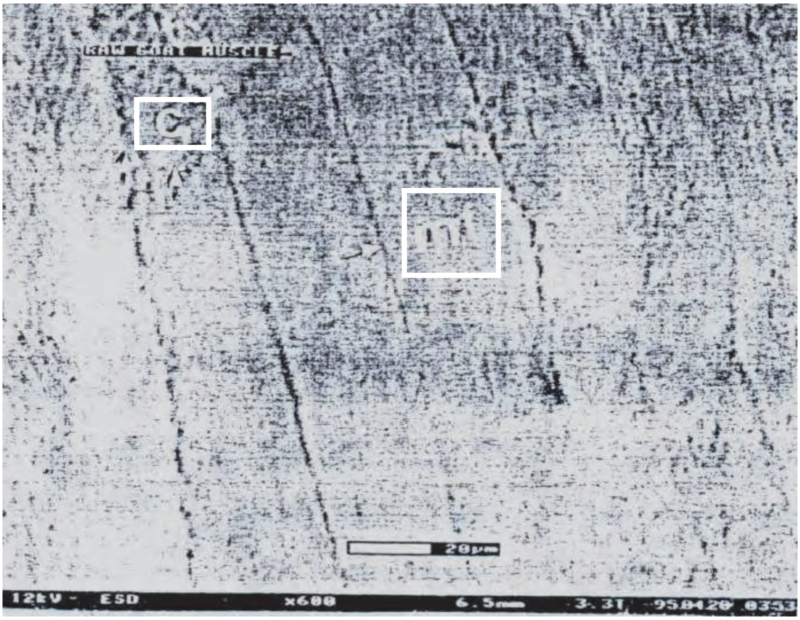

Fig. 4. Another illustration of structure of raw goat SM muscle by ESEM (c: collagen, mf: muscle fiber).

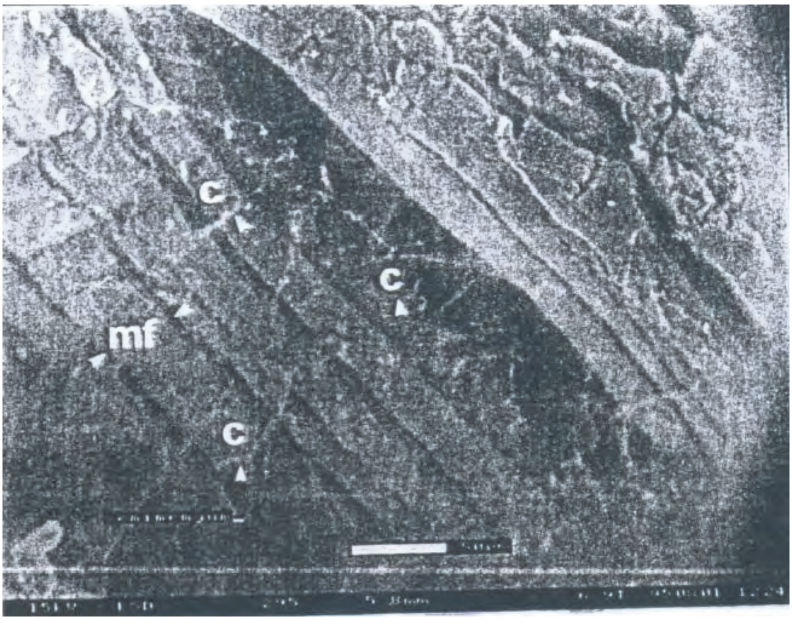

Fig. 5. Structure of SM muscle using Miller stain. Collagen network appears bright (c: collagen, mf: muscle fiber).

As shown in Fig. 6 collagenous fibers are clear and appeared as a white network with covering bundles of SM muscle fiber. Cross section of SM muscle has been shown in Fig. 7 In application of ESEM, it is important to consider possibility of dehydration of the fresh tissues which might occur in the sample chamber. There is also the possibility which might occur from electron beam on the sample if the operating system is not clearly set and adjusted prior to imaging. To prevent dehydration and localized beam damage in correctly specimen, it can be maintained in semi-wet condition by monitoring the system at a lower voltage (2-5 kv) or at lower temperature by applying a cooling step (-20 to 30 °C) and at higher gas pressure up to 20 torr. (Uwins, 1994).

Fig. 6. Cross section of SM muscle.

In the study of the microstructure of SM muscle, more damage was observed when domestic microwave heating was used. This resulted in more shrinkage and breakdown in the SM muscle. The myofibril surface did not seem to be normal but showed little evidence of tissue damage. The cross section of SM (Fig. 8) illustrated the damage at the surface of specimen, further application of the ESEM illustrated that domestic microwave heating causes more physical damage to connective tissue and myofibril elements compared to roasting technique (Fig. 9). Results showed that domestic microwave heating caused little hydrolysis in connective tissue.

Fig. 7. Environmental Scanning Electron Microscopy of domestic microwave heated SM muscle. Surface damages were shown by arrows in cross section view.

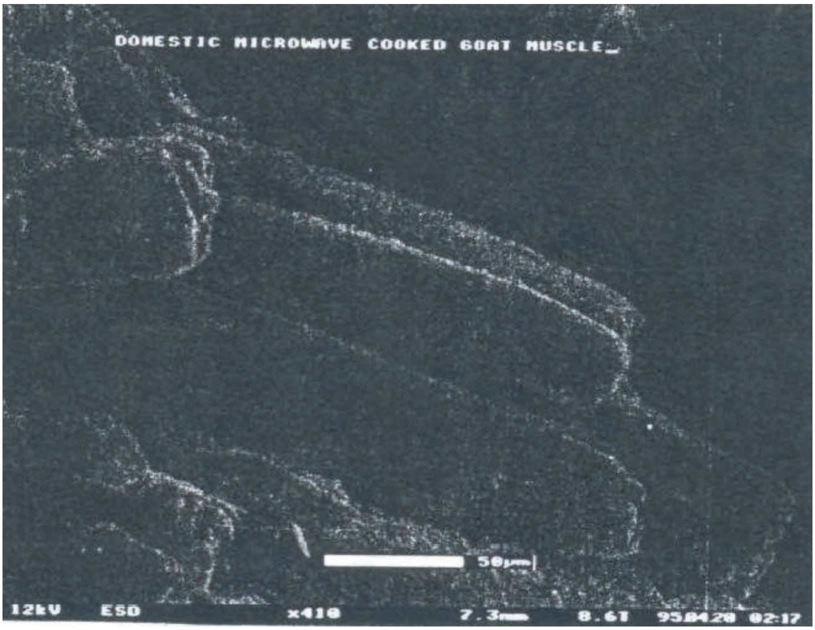

Fig. 8. Another view of domestic microwave cooked (700 W) SM muscle by ESEM.

Fig. 9. Effect of conventional heating on SM muscle by ESEM. Transverse breakage was shown by arrows.

As a result of these investigations, it is possible to identify and characterize the fine structure of lamb, veal and goat semimembranosus muscle. Moreover to study and compare the effect of various heat treatments such as conventional and microwaves at two wattages levels (700 and 12000 W) on structure of this muscle. In lamb and goat SM muscles results show that microwave heating cause more structural damage at both levels comparing to conventional heating and heat distribution in microwave heating is responsible for the surface damage to muscle fiber and separation of some parts and denaturation of collagen. While in veal SM muscle because of original texture of the veal, results are different. Domestic microwave heating caused less physical damage to the connective tissue network and myofibril elements comparing to the conventional cooking results. Further research is still required to study the fine structure of semimembranosus or other muscle from various animals (Yarmand & Homayouni, 2009; 2010).

5.3 CSLM

Confocal microscopy was described at 1957 (Fig. 10). It has some advantages in composition with conventional light microscopy. Since the laser as a light source was not invented on that time, it was not possible to improve Confocal Microscopy. In addition lack of a suitable computer due to collecting data of image presentation, also causes a problem in the progress of this instrument. Reflection Scanning Light Microscopy (TRSLM) was made as the second confocal system. For the first time the sectioning effect in confocal microscopy (CM) was presented. Generally the major construction of the second microscope was entirely different from the first microscope suggested by Minsky (1957). This instrument was not satisfactory because of poor image quality and resolution.

In spite of the sectioning in TRSLM, the original could not be called as three-dimensional image (Sheppard and Wilson, 1978).
Early presentation of the imaging abilities and the initial improved confocal was displayed in publication by Brakenhoff (1979). Sheppard et al (1977) and Brakenhoff (1979) both employed laser as a light source. They also used a mechanical scanning that moves the specimens through the stationary confocal point. The nucleoid structure of the Echerichia Coli was studied by Brakenhoff microscope. Many experiments described the advantage of the combination of fluorescent techniques and high aperture confocal microscopy for the 3D imaging of biological structure. Fluorescence confocal microscopy was used for food emulsions and nerve cells. Fluorescence confocal microscopy also applied in the investigation of living cells. Calcium probes for the study of calcium spread in cells and searching SH groups (Brakenhoff, 1979; Grynkiewicz et al., 1985; Wijnaeadts Van Resandt et al., 1985).

Fig. 10. Confocal microscopy

Confocal scanning laser microscopy has been applied as a new technique in the study of microstructure of food during recent years. sheppard and Gu (1993) applied confocal microscopy for presentation of three dimensional fluorescence images of muscle fibers. According to them, a simple model of striated muscle fiber is quite useful for such image modeling. Fluorescence confocal scanning laser microscopy (FCSLM) model DMRBE was used for study of structure of goat SM muscle after various heat treatments. All specimens were stained with Picro Sirius Red technique. Confocal scanning laser microscopy has several advantages over conventional microscopes. According to Brakenhoff et al., (1988) Confocal scanning light microscopy forms a bridge between conventional light microscopy with its limited resolution (but capable of imaging hydrated, possibly live, specimens) on the one side, and electron microscopy with its higher resolution on the other. The principal of the basic confocal microscope has been explained by Sheppard and Choudhury (1977). This microscope might be operated in two techniques: reflection or in fluorescence. Optical sectioning and 3D reconstruction might be considered as a very

important superior of confocal microscopy. Optical sectioning is non-invasive and allows for the imaging of thick objects and a three dimensional reconstruction of the sample. The Performance of confocal microscope suggests new possibilities in microstructure studies of food by the disturbance free visualizing of the three-dimensional internal structure. Such a set of observations from different sections of a muscle specimen will present complete information about the three-dimensional microstructure of semimembranosus muscle. Confocal microscopy is able to provide X-Z images which are images perpendicular to normal image and finally provide ability to observe the depth of materials. Despite that, using CSLM has another benefit that of improved resolution, superior fluorescence and improved quality of sample. Improved sample quality caused by optical sectioning which diminishes limitations of physical sectioning. The system is equipped with fluorescence techniques which exposes the specimen to the fluorescence. Fluorescence techniques provide the ability for the CSLM to choose CSLM the wavelength band of fluorescence light which contributes to better images. Confocal microscopy can show that the size of fat droplets varies with gum type in minced ostrich meat batter. In chicken meat gels, it showed that low-fat protein gels obtained by pressure and containing microbial transglutaminase had a more compact and homogeneous microstructure compared with controls that were pressurized but contained no MTGase (Chattong et al. 2007; Trespalacios and Pla, 2007).
CSLM used in fluorescence gives an excellent perspective of relationship between muscle fiber and collagen network including endomysial collagen fibers. An image of raw SM visualized by three dimensional construction of this muscle is shown in Fig. 11.

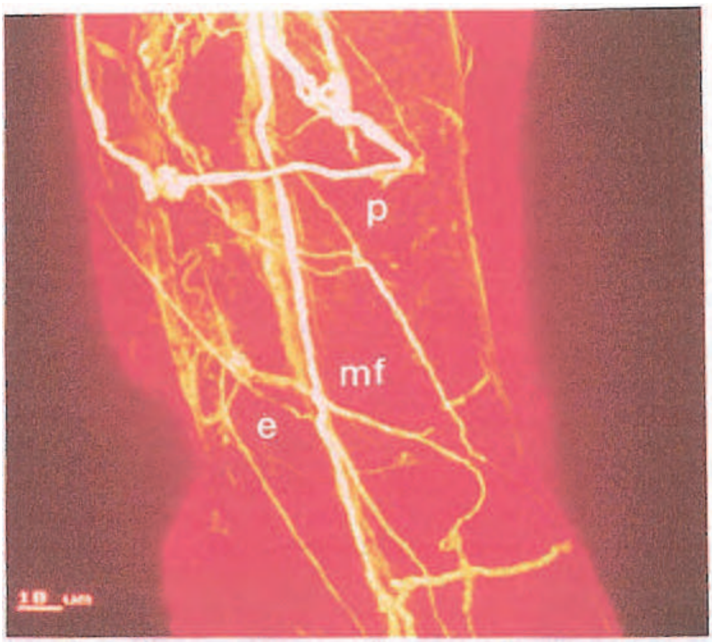

Fig. 11. Illustration of raw SM muscle of goat by FCSLM. Perimysial (P) and endomysial (e) collagenous network were appeared. Mf: muscle fiber.

As mentioned previously optical sectioning through specimen is responsible for the 3D construction of images. Fluorescence confocal scanning laser microscopy (FCSLM) has been used in the study of semimembranosus muscle in goat (Yarmand & Homayouni, 2009; 2010). Four treatments raw (control), conventional and microwave heating at two power levels 700 and 12000 W were examined. As mentioned previously the main advantage of CSLM is the capability of preparing three dimensional pictures which enables the relative distribution of connective tissue to be visualized. Because of the ability to 3D image muscle when heat treatment reduces the length or width of a muscle structure, it will be apparent in the images. Fig. 12 represents how FCSLM build this construction. Overlap of sequence images in Fig.12; give us better view of 3D images which illustrate the depth of material by providing X-Z images in final observation. As described earlier in the principle of confocal scanning electron microscopy, X-Z images are perpendicular to normal images which provide the ability for this microscope technique to observe the depth of material.

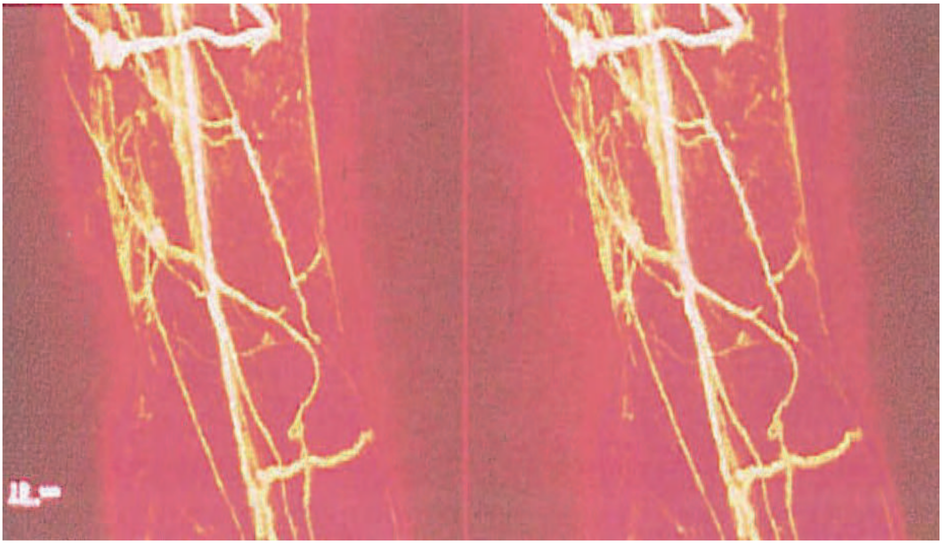

Fig. 12. Sequence of images from raw SM muscle of goat. Overlap of these images visualized better view of 3D images in FCSLM.

Conventional heating micrograph shows less damage to the structure of SM muscle (Fig. 13 and Fig. 14). As it shows in Fig. 13, muscle fiber appeared red which surrounded by a collagenous tissue network. Connective tissue is seen as fluorescent yellow color. Sequences of images indicate the manner of 3D construction of conventional micrographs by FCSLM. In the confocal pictures the signal from collagen fluorescence stained with Picro Sirius Red give a yellow golden hue whereas the muscle fluorescence is illustrated as red. Using the fluorescence property with CSLM allowed us to select the wavelength band of fluorescence light contributing to the image. In this way, we are able to distinguish various structures inside the SM muscle and study their 3-D relationships. Conventional heating micrograph shows less damage to the structure of SM muscle (Fig. 13). As it shows in Fig. 13, muscle fiber appeared red which was surrounded by connective tissue network. Connective tissue seems fluorescent with yellow color.

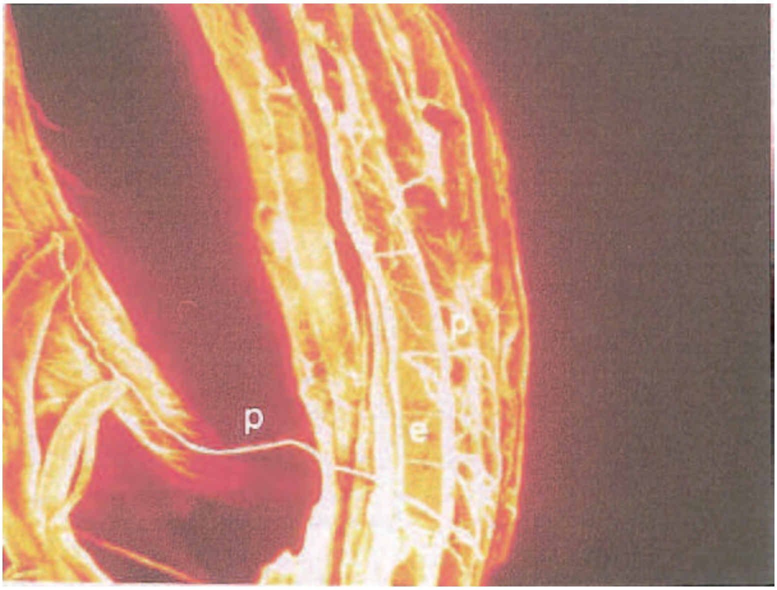

Fig. 13. Conventional heating image of goat SM muscle by FCSLM Perimysial (p) and endomysial (e) connective tissue.

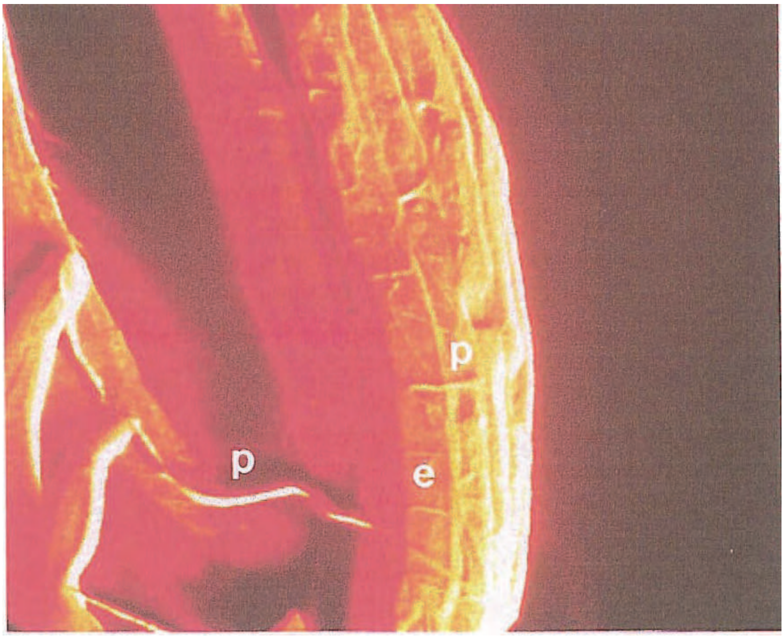

Fig. 14. Another view of conventional heating of goat SM muscle. Perimysial (p) and endomysial (e) connective tissue have been shown by FCSLM.

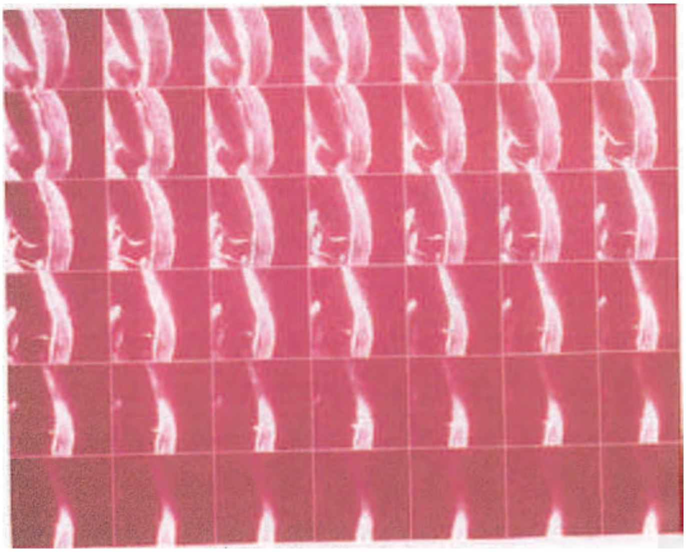

Fig. 15. Demonstration of domestic microwave heated of goat SM muscle by FCSLM. Separation of connective tissue network has been shown in micrograph. Mf: muscle fiber, c: connective tissue.

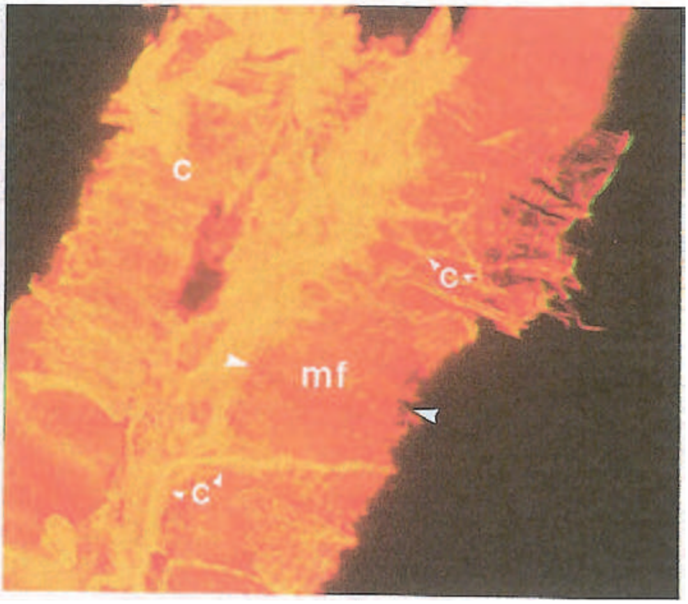

Fig. 16. Presentation of industrial microwave heated of goat SM muscle by FCSLM. Fluorescence Fluorescence property of perimysial (p) and endomysial (e) connective tissue have been illustrated. Arrows indicate degradation and breakdown area of muscle fiber. mf: muscle fiber, scale bar: 10

More damage was observed in the structure of goat SM muscle after using industrial microwave heat treatment. Degradation and breakdown also appeared in microwave heating (Fig. 15 and 16). This result is in agreement with environmental scanning electron microscopy of goat SM muscle. Fig. 17 illustrated another view of industrial microwave cooked. The same result is provided by FCSLM for domestic microwave muscle. The sequence of images provided as a set of observations by fluorescence confocal scanning laser microscope, is shown in Fig. 12. It seems that in raw (control) specimen, fluorescence property of connective tissue is more apparent and it seems that it slightly decreases after heating by various techniques. This reduction was visualized in Fig. 13 and appeared more in microwave heating Fig. 15 and 16. This suggests that particular heat transfer occurred. However, still further researches are needed in order to understand the effect of heat on fluorescence property of collagen.

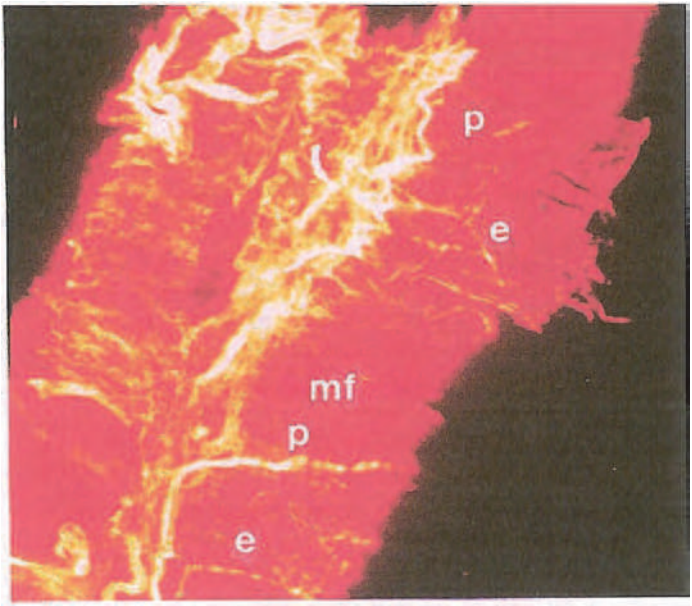

Fig. 17. Another microscopic view of industrial microwave heating of goat SM muscle.
mf: muscle fiber, c: connective tissue, scale bar: 10 microns.

6. Conclusion

Microstructural evaluation was employed to study the qualitative parameters of meat and meat products. Microscopical techniques are used to characterize meat structure. Optical microscopy can be used for observation of fat globules distribution and protein gel in sausages. Among microscopical methods, the environmental scanning electron microscopy (ESEM) has its own advantages for evaluation of microstructural changes in meat especially for comparing the effect of various heat treatments. Because of large applications of microwave in meat processing (tempering, thawing and cooking) as well as quality control of meat and meat products, more studies are needed to investigate the effects of microwave processing on these products.

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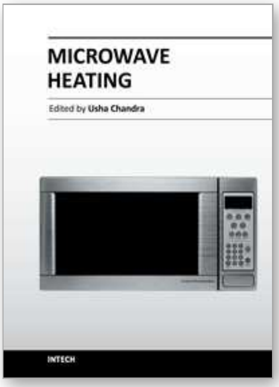

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The Microwave heating has not only revolutionized the food industry but also has extended its wings widely towards its multidimensional applications. Thus it has opened new vistas of potential research in science and technology. The book is compiled into Seventeen Chapters highlighting different aspects varying from epistemological discussion to applicability of conceptual constructs. The inclusion of discussion on the avenues in the field of Chemistry, Health & Environment, Medical Sciences and Technology makes it an exquisite work for the aspirant Researchers. As the text book for the beginners, it is designed fundamentally to be a reference monograph to the experts providing a passage for future research. The plethora of literatures are available on Microwave Applications but they seldom direct their readers to concentrate on the key aspects behind the success in microwave applications in different fields. Here is the attempt to fill up the gap with this book.