Novel Technologies and Systems for Food Preservation

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Chapter 4
Energy Efficiency in Meat Processing

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ABSTRACT

Energy conservation plays a vital role towards sustainable development of meat processing. Energy costs for many meat plants represent the fourth highest operational cost. In meat processing, moderate levels of both electrical and thermal energy are consumed in wide range of processes and applications. However, energy efficiency improvement in the meat processing industry have been a focus to increase the sustainability of meat processing in the past decades. This chapter started with the examination of the energy use in meat processing facilities. The emerging energy-efficient technologies for meat processing were discussed in detail. Energy requirement for well-cooked meats varies with cooking method, appliances, and consumer behavior. Energy consumption reduction during meat cooking may have an influence on global energy requirement. Selection of cooking method, fuel, and cookware are beneficial for reducing the carbon footprint of the cooking unit. This chapter also presents the effects on quality characteristics of meat and meat products by different cooking methods.

MEAT PROCESSING: OVERVIEW

Meat and meat products are rich sources of nutrients including, fats, proteins, vitamins (vitamin B12) and minerals (zinc and iron) and forms an essential part of the diet and consumed across in many parts of the world (FAO, 2012). Ritchie and Roser (2018) highlighted that global meat production had increased 4-5 folds since 1961 and the Figure 1 depicts that movement. However, this trend of meat production and consumption is on the rise in both developing and developed nations.

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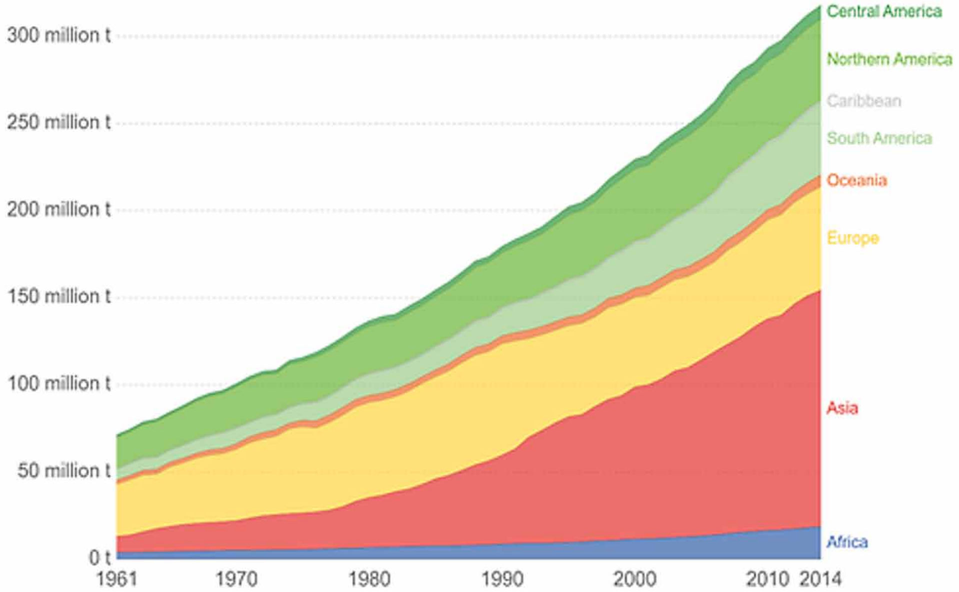
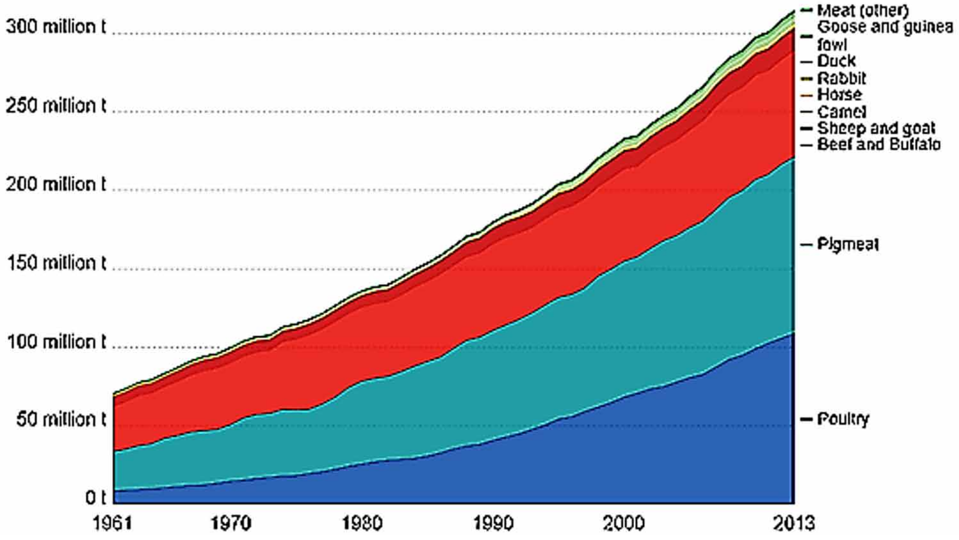
Figure 1. Total meat production in tonnes excluding offal & slaughter fats
(Ritchie & Roser, 2018)



Meat production by livestock type has also changed dramatically since 1961 as shown in the Figure 2.

Slaughtering of livestock is an important industry in most of the countries to produce meat and meat products. It involves stunning, bleeding, dehiding, dehairing/defeathering, evisceration, dressing and washing. Depending on the customer requirements it may also involve the deboning process (Hui, 2012). During the slaughtering process both edible (e.g. livers, gizzards) and inedible products (e.g. hides,

Figure 2. Meat production by Livestock Type
(Ritchie & Roser, 2018)

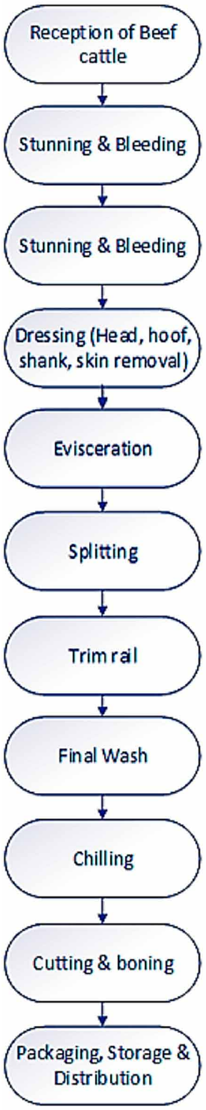


feathers) are produced. Figure 3 presents a flowchart for the basic processes involved in slaughtering and processing of beef.

- **Reception of Beef Cattle**: Beef cattle are delivered on a specially designed lorries to the slaughterhouse and kept in the holding area where cattle are washed and rested for one or two days.
- **Stunning and Bleeding:** The cattle are led to the stunning area where they are stunned using electric shock or bolt pistol to make animal unconscious without any discomfort or excitement. They are then chained by their rear legs and mounted on overhead rail. Using a sharp blade their carotid arteries and jugular vein are severed to allow all the blood present in the animal to flow out in a trough.
- **Dressing**: In this process unwanted parts such as skin, head, hair and hoofs are removed using machines in larger slaughterhouses or by hand in smaller operations. Antimicrobial interventions such as hot/ambient water wash, organic acid wash, steam vacuuming and bunging is carried out on the carcass to reduce the microbial activity. Steam vacuuming is used to remove any contamination from the carcass and bunging is to avoid contaminating the carcass with faecal material.
- **Evisceration**: Evisceration is the process to remove internal organs from the carcass. Care must be taken so that internal organs such as stomach and intestines are carefully separated without contaminating the carcass with faecal material.
- **Splitting**: In this stage the carcass is split with a saw which allows inspection of the carcass for any disease conditions which can be unfit for human consumption.
- **Trim Rail**: Carcass parts which are undesirable or parts which possesses quality issues are removed by trimming.
- **Final Wash & Chilling**: In this step the carcass undergoes final wash to remove any further contaminations. The carcass is weighed, marked, branded and sent to chillers. Sending it to the chillers inhibit the growth of harmful microbial pathogens. Appropriate temperatures are maintained in the chillers to ensure quality and safety of the carcass.
- **Cutting and Boning**: At this point the carcass is chopped or deboned as per the customer requirements and packed.
- **Packaging, Storage and Distribution**: This is the final step where product is packaged with correct specifications (expiry date, description), stored and sent for distribution.

Meat and meat products have the greatest environmental impact of all products in the food and drink area. In meat plants, energy costs represent the fourth highest cost (after raw materials, waste management and labour (AHDB, 2011). There are some significant challenges in meat processing industry prevent this sector from becoming more energy-efficient and sustainable, which includes evaluation of energy saving measures, implementation, and lack of use of alternative sources of energy (Brunner, Fluch, Kulterer, & Glatzi, 2014) .

Figure 3. Flowchart for beef processing
(FAO, 1996)



ENERGY-EFFICIENT TECHNOLOGIES FOR MEAT PROCESSING INDUSTRY

As described in the above section, the global meat production and consumption is on the rise and also the energy required by the meat industry. However, at the same time consumers want to have access to high quality, safe and convenient meat products with minimal processing and preserving the freshness, natural flavour and taste of the product (Hugas, Garigga, & Monfort, 2002). In order to achieve this meat industry came up with many preserving techniques which are low in energy consumption but still effective against pathogenic and spoilage micro-organisms.

The energy required by the meat processing industry can be distinguished between thermal and non-thermal processing technologies (Table 1).

Table 1. Meat processing technologies

Non-thermal technologies	Thermal Technologies
High Hydrostatic pressure	Microwave
Pulsed electric fields	Radiofrequency
Ultrasound	Ohmic heating
Ultraviolet	Induction heating
Irradiation	
Cold plasma	
Dense Phase carbon dioxide	
Ozone	
Chemicals	

Novel Thermal Processing Technologies

Microwave (MW)

MW heating is used in meat processing for tempering, thawing, and cooking of meat (Yarmand & Homayouni, 2011). Tempering of frozen meat using MW energy allows easier slicing of meat and has been demonstrated that it results in higher product yield as it minimises the evaporative and drip losses as compared to other conventional meat tempering processes. Under appropriate conditions thawing took lesser time compared to convective thawing at ambient temperature. Commercialisation of MW thawing was not that successful in meat industry with respect to MW tempering. MW cooking is relatively newer method of cooking meat and has been widely accepted since it takes less time to reach endpoint temperatures for roasts when compared with conventional methods. MW cooking allows holding of vitamins such as retinol, thiamine and riboflavin compared with other higher cooking temperature (Zhang, Lyng, & Brunton, 2006).

Radiofrequency (RF)

RF technology is being deployed by meat industry because of its higher penetration depth, uniform heat distribution and low energy consumption. Its been successfully used in the industry to sterilise, pasteurise and disinfect meat products (Jojo & Mahendra, 2013). For e.g., Wang et al.(2012) used RF energy to process meat lasagna and demonstrated that there was no much temperature difference in the lasagne ingredients (meatballs, mozzarella cheese and sauce). There was adequate heat transfer reducing differential heating and product quality was unaffected. Another research conducted by Kirmaci and Singh (2012) established that RF cooking time for Chicken breast was reduced by 42.4% when compared to Water bath cooking and Laycock et al. (2003) illustrated that RF cooking of ground beef, comminuted meat and muscle was 5.83, 13.5 and 13.25 mins respectively when compared to 151, 130, 109 mins in water bath.

Ohmic Heating (OH)

OH is a thermal process generating internal heat in a meat product in a uniform way and is based on the principle that most of the food products are able to resist to the flow of electric current (Pereira & Vicente, 2010). OH technology usually requires electrodes to be in contact with foods and due to its very quick heating rates allows meat to reach its pasteurisation temperature in short time (De Halleux, Piette, Buteau, & Dostie, 2005). They further demonstrated that cooking time for Bologna hams were reduced by 90-95% when compared to the traditional method of smoking hams. And, if the process is replicated in industries, it would result in energy efficiency greater than 90% and reduction in energy consumption of 82 to 97% compared to conventional method of smoking hams.

Induction Heating (IH)

IH is the process of heating usually a metal via electromagnetic induction. It is often used in cooking processes where the meat products are placed in a container which is ferromagnetic in nature. This process often involves the danger of product damage due to burning, as high heat transfer from the hot surfaces (Varghese, Pandey, Radhakrishna, & Bawa, 2014).

Non-Thermal Processing Technologies

High Hydrostatic Pressure (HHP)

HHP application on food is a widely researched topic and this method involves exposing food to pressures between 100 to 1000 MPa. HPP causes denaturation of proteins resulting in inactivation of enzymes and microorganisms (Sun & Holley, 2010). This technology offers various benefits such as: uniform pressure application to food product creating homogeneity, minimum heat impact, similar shelf-lives to thermal pasteurisation and less energy needed to compress a solid or liquid food product to 500 MPa with regards to heating at 100°C (Pereira & Vicente, 2010). HHP is commercially deployed in various food industries including cooked meats, seafood and fish.

Pulsed Electric Fields (PEF)

PEF technology involves delivery of pulses of high voltage to the product placed between a pair of electrodes and this action results in inactivating microorganisms without any changes to nutritional, flavour, taste and quality (Faridnia, Bremer, Burritt, & Oey, 2016). PEF accelerates curing process of meat, enhances drying and reduces the activity of microorganism but still has a long way to cover to become a commercial reality in the meat processing industry (Bhat, Morton, Mason, & Bekhit, 2018).

Ultrasound (US)

US technology is an emerging technology with potential to accelerate the process of tenderisation, maturation and mass transfer, reduction in cooking energy and enhancing the shelf-life but at the same time preserving the quality and functional properties (Alarcon-Rojo, Janacua, Rodriguez, Paniwnyk, & Mason, 2015). This technology uses sound waves higher than those that can be detected by human ears

(20kHz). The sound travels through a medium generating wave of compression and rarefaction of the particles resulting in formation of cavities and these cavities become unstable and collapse releasing high temperatures and pressures (Chemat, Huma, & Khan, 2011).

Ultraviolet (UV)

UV is a non-thermal technology and highly utilised in surface treatment of food. UV technology popularity and acceptance are increasing due to its effectiveness against pathogenic and spoilage microorganisms as well as low maintenance and environment friendliness (Koutchma, 2008). However, its not that efficient in penetrating the solid foods and can be ineffective against pathogens which are deep inside the meat (Degala, Mahapatra, Demirci, & Kannan, 2018).

Irradiation (IR)

Gamma IR technology is very effective for protecting food against contamination but its acceptability by consumers is still very low (Hugas, Garigga, & Monfort, 2002). Kanatt, Chander, and Sharma (2005) investigated effect of radiation on meat products and their shelf-life. The results from this research demonstrated that shelf-life of the products increased by more than 2 weeks without affecting the sensory qualities of the products.

Cold Plasma (CP)

The application of CP technology on bacterial spores is more effective than compared to other techniques like heat, chemicals and UV treatment while maintaining sensory attributes and freshness (Thirumdas, Sarangapani, & Annapure, 2014). CP technology is effective on range of the microorganisms and spores in shorter periods of time and is an alternative technology for surface sterilisation and act as a disinfectant (Philip, Saoudi, Crevier, Moisan, Barbeau, & Pelletier, 2002). Until now in order to decontaminate food, CP technology needed to work at room temperature and this condition was achieved only under vacuum which was expensive and not convenient. But, recent developments in CP technology allows production of plasmas through utilisation of simple and cheap equipment having both spatial and temporal stability at ambient temperature and atmospheric pressure (Kogelschatz, 2002).

Dense Phase Carbon Dioxide (DPCD)

DPCD technology is a cold pasteurisation method to inactivate microorganisms and affects enzymes under pressure below 50 MPa without having any undesired effects of heat and retaining the freshness, nutritional and sensory attributes (Damar & Balaban, 2006). It is continuous technique that utilises pressure in combination with CO_2. The CO_2 used in solvent form is widely used in many food applications as it is non-toxic, chemically inert, non-flammable, inexpensive and no residues are left behind (Ferrentino & Spilimbergo, 2011).

Ozone (O_3)

Ozone is a powerful oxidant and disinfecting agent. Ozone has been used in food industry for treating food surface, equipment, lowering biological and chemical oxygen demand (Guzel-Seydim, Greene, & Seydim, 2004). Researchers successfully used ozone as disinfectant for poultry carcasses (Sheldon & Brown, 1986; Yang & Chen, 1979). Ozone application has resulted in increase in shelf-life of the products and it leaves no residue behind since it decomposes quickly (Khadre, Yousef, & Kim, 2001).

Chemicals

The application of Chlorine based chemicals are widely used in the meat processing industry. Acidified sodium chlorite, alkyl dimethyl benzyl ammonium chloride, chlorine dioxide and sodium hypochlorite are some of the disinfectants added to water to reduce microbial contamination during poultry processing (Guastalli, Batista, Souza, Guastalli, Lopes, Almeida, et al., 2016). Electrolysed water which reduces the microbial growth and increases the shelf-life of meat products but at the same time there is concern regarding the applicability of this process due to stability of chlorine, corrosion resistance and chlorate residues (Wang, Duan, Wu, Xue, Xu, & Zhou, 2019). Lee, Oh, Chung, Choi, Myeong, Song, et al. (2018) demonstrated the applicability of chlorine dioxide gas (CIO_2) as a disinfectant on livestock carcasses and equipment. Nitrate and nitrite which are used for curing meat products inhibits growth of microorganisms but at the same time forms carcinogenic nitrosamines in human stomach (Honikel, 2008).

ENERGY FOR MEAT PROCESSING

A research conducted by Ramirez, Patel, and Blok (2006) showed that meat processing sector in four EU countries (France, Germany, The Netherlands and The United Kingdom) consumed energy between 40-60%. They further stated that except France (mostly used electricity) the other three countries used most of the fuel in the form of natural gas to drive their meat sector but there is an increasing trend towards the use of electricity. Fossil fuels are used mainly for heat processing while electricity for refrigeration purposes.

As per the survey report published by AHDB (2011), a slaughterhouse in the UK typically uses 50-80% of energy in the form of electricity while the rest 20-50% comes from thermal energy. Other than refrigeration, electricity is used for generating compressed air, ventilation purposes, lighting and powering of the machines such as saws, hoists, conveyors, packing lines, electrical stunning and rendering purposes. While thermal energy (from natural gas and oil) is used for boilers to provide heat and hot water which is then used for processes such as scalding, sterilisation of surfaces and equipment and cleaning activities. The survey further states that on average 775kWh of energy is needed to produce a tonne of beef and 685kWh of energy to produce a tonne of sheep meat. Pig abattoirs require 80% of its energy in the form of thermal energy as compared to beef and lamb abattoirs which need 30-50% of its energy in the form of thermal energy.

Energy Use of Beef Processing Plants

Table 2 illustrates the energy use of beef packing plants around the world. Ziara (2015) stated that energy use of these plants varies due to many factors such as size and location of the plants, automation of the production processes, capacity, machinery age and efficiency, insulation, weather and temperature.

In meat plant substantial energy savings can be made almost immediately with little or no capital investment, through simple housekeeping efforts. In addition to reducing a plant's demand for energy, there are opportunities for using more environmentally benign sources of energy. Opportunities include replacing fuel oil or coal with cleaner fuels, such as natural gas, purchasing electricity produced from renewable sources, or cogeneration of electricity and heat on site. For some plants it may also be feasible to recover methane from the anaerobic digestion of high-strength effluent streams to supplement fuel supplies (Brunner, Fluch, Kulterer, & Glatzi, 2014).

IMPORTANCE OF MEAT COOKING

Meat and meat-based products are cooked before being eaten. Cooking step is critical for destroying foodborne pathogens, assuring microbial safety and achieving meat quality. Cooking method has great impact on eating quality of meat, and energy consumption is important parameter to consider while selecting the cooking method (Pathare & Roskilly, 2016). Eating quality of meat is mainly affected by applied cooking method. The quality characteristics of meat products change considerably depending on the type and intensity of the heat treatment applied. (Bejerholm & Aaslyng, 2004a). Cooking of meat results in better aroma and also, the cooked meat is more tender compared to raw meat (Oz, Kızıl, & Çelık, 2016). Traditional methods for cooking meat products involve heating the product by immersion in hot water or by steam cooking. In such cooking processes, heat is predominantly transferred by convection from the cooking media to the product surface and then by conduction from the surface to the

Table 2. Energy use of beef packing plants

Year	Reported Energy Use	Calculated equivalent use	Location	Reference
1996-1997	807017 BTU/head	851 MJ/head	United States	(Parker, Auvermann, Stewart, & Robinson, 1997)
1999	70-300 kWh/head	252-1080 MJ/head	Denmark	(Hansen, Christiansen, & Hummelmose)[a]
2002	2.4 GJ/tHSCW[b]	1090 MJ/1000 lb. BW	Australia	(Pagan, Renouf, & Prasad, 2002)
2006	60 kWh/tonne product 216 MJ/tonne product	196 MJ/1000 lb. product	Finland	(Ramirez, Patel, & Blok, 2006)
2008	269-279 kWh/tonne product 2.10-2.26 GJ/tonne product	1391-1480 MJ/1000 lb. product	Poland	(Kowalczyk & Netter, 2008)
2012	1723 MJ/tonne products	781 MJ/1000 lb. product	Poland	(Wojdalski, Dróżdż, Grochowicz, Magryś, & Ekielski, 2013)

[b]tHSCW = tonne of hot standard carcass weight

Sourced from (Ziara, 2015)

geometrical center of the products. This could lead to overheating of the surfaces while waiting for the interior to reach the required temperature (Li, Sun, Han, & Yu, 2017). The choice of appropriate cooking techniques relies on the type of meat, the amount of connective tissue, size and shape of the meat. The different meat cooking methods commonly used are discussed below.

Oven Cooking

Oven cooking is widely used in commercial processing and food service operations as well as home cooking (Isleroglu, Kemerli, & Kaymak-Ertekin, 2015). Quality attributes and microbial safety of products have been affected by oven cooking or roasting (Goñi & Salvadori, 2010). An oven empowers heating of meat at raised temperatures normally up to 250°C. Rapid rate of heating due to high cooking temperature reduces the total cooking loss of meat. (Palka & Daun, 1999). The reduction in total cooking loss is important as meat promotes higher solubilisation of intramuscular collagen based connective tissue leading towards tenderisation due to high water holding capacity. Maintenance of moisture in the product during cooking helps improve juiciness (Ritchey & Hostetle, 1965). During roasting, the first period of toughening happens because of the denaturation of myofibrillar proteins. Subsequently, toughening is further escalated from the shrinkage of intramuscular collagen, followed by a final increment in toughness when the shrinkage and dehydration of the myofibrillar proteins take place (Bailey & Light, 1989).

In oven cooking, surface dehydration prevention and cooking time reduction have been done by coupling the forced air convection method with steam injection in the oven chamber (Murphy, Johnson, Duncan, Clausen, Davis, & March, 2001). Application of air/steam treatments accomplished the exact heat control of a convection oven and the efficiency of steam cooking with the ensuing reduction lessening in cooking time (Chiavaro, Rinaldi, Vittadini, & Barbanti, 2009). Steam induction into the oven chamber during cooking makes heat and mass transfer more complex as it increases the heat transfer and the surface water evaporation process is modified. Generally the oven temperatures higher than 150°C has been used for meat roasting, however lower cooking temperature could reduce energy with beneficial effect for domestic and commercial catering operations. And the induction of steam accelerated the cooking process, increases the overall heat transfer coefficient and reduces the cooking time (Vittadini, Rinaldi, Chiavaro, Barbanti, & Massini, 2005). Murphy et al. (2001) reported that the heat flux is firmly related with the relative humidity of the oven air and results in diverse meat heating profiles.

High cooking temperatures enhance colour and flavour and lessens the cooking times however diminish meat tenderness and juiciness. On the other hand, high relative humidity builds the heat transfer and meat juiciness yet lessening flavour and colour development (Rinaldi, Chiavaro, & Massini, 2010).

Frying

Frying is a cooking technique where fat or oil is utilized as the heat transfer medium, in direct contact with the food (Varela, Mosquera, Bender, & Morton, 1988). Heat is transmitted by contact between the pan and the meat. Frying is complex process due to coupled heat and mass transfer between meat and frying medium. Simultaneous heat and mass transfer of oil and air promote a number of chemical changes, such as moisture loss, oil uptake, crust formation, gelatinization of starch, aromatization, protein denaturation and colour change via maillard reactions, hydrolysis or oxidation, and oil polymerization (Mir-Bel, Oria, & Salvador, 2012).

Frying temperature is a crucial component to the extent meat flavour, cooking time and weight loss of products. The cooking time is generally short due to the high frying temperature, and the meat surface gets to be brown due to maillard reaction.

Sous Vide Cooking

Sous vide is defined as the method of heating raw meat packed inside a vacuum pouch in a water bath at a specified temperature (Vaudagna, Sánchez, Neira, Insani, Picallo, Gallinger, et al., 2002). In sous vide cooking, typical temperatures around 50-85°C are used, thus it requires longer heating times compared to conventional cooking methods. Sous vide cooking differs from traditional cooking methods in two fundamental ways: the raw food is vacuum-sealed in heat-stable, food-grade plastic pouches and the food is cooked using precisely controlled heating. Cooking takes place at a specific temperature is of particular interest for meat, which owe their textural properties mainly to the complex structural arrangement and water binding capacity of muscle proteins. Upon heating, these proteins denature, losing their native conformation and causing a change in the texture of the product. Most relevant to sous-vide cooking is the fact that different proteins, being responsible for different properties of the final product (tenderness, juiciness, etc.), denature at different temperatures. This allows tailoring the properties of the food by selectively denaturing some proteins while leaving others intact.

Sous vide cooking maintained the lower temperature, which minimises the temperature gradient and reduces the damage to heat sensitive proteins and supplements. It also reduces cooking loss and preserves the juiciness (Díaz, Nieto, Garrido, & Bañón, 2008; Vaudagna, et al., 2002). Low temperature in sous vide method has a positive effect on meat tenderness. And the extended cooking time builds collagen solubility (Bejerholm & Aaslyng, 2004a). In sous vide cooking the tenderisation of the connective tissue takes place through the solubilisation of the intramuscular collagen inside the moist in-pack environment (Garcia-Segovia *et al.*, 2007; Holcomb & Kalab, 1981). Sous vide cooking is promoted for its ability to retain nutrients, enhance flavour and texture in a manner that conventional roasting can't deliver (Mortensen, Frøst, Skibsted, & Risbo, 2012).

Ohmic Cooking

Ohmic cooking process is based on passing electric currents through the food causing internal heat generation. It is a promising technique compared to conventional meat cooking as it is considerably fast (Yildiz-Turp, Sengun, Kendirci, & Icier, 2013). It involves the utilization of the electricity to a food material, bringing about volumetric heat generation (Stirling, 1987). The system depends on the entry of electrical current through a food item that has electrical resistance (Icier & Ilicali, 2005). Electrical energy is converted into the heat and the heat generation relies on the voltage gradient and electrical conductivity (Sastry & Li, 1996). And it resulted in efficient rising in internal temperature of food (Wang & Farid, 2015). wherein the electrical energy is converted into heat and caused efficient rising of the interior temperature of the food.

Ohmic cooking in meat products resulted in faster cooking, less power consumption and safer product (Özkan, Ho, & Farid, 2004). Ohmically cooking produces a firmer sample than conventional cooking (Bozkurt & Icier, 2010b). Ohmic heating resulted in cooking loss reduction and improved juiciness (Zell, Lyng, Cronin, & Morgan, 2009). Many researchers showed that ohmic heating could be used as a cooking process for producing safer meat products either alone or in combination with conventional cooking methods (Bozkurt & Icier, 2010a, 2010b; Icier, Sengun, Yildiz Turp, & Arserim, 2014; Özkan, Ho, & Farid, 2004; Shirsat, Brunton, Lyng, McKenna, & Scannell, 2004; Zell, Lyng, Cronin, & Morgan, 2009). However, ohmic cooking is an inefficient cooking method for desirable changes in surface colour and texture in meat products (Bozkurt & Icier, 2010a, 2010b; Yildiz-Turp, Sengun, Kendirci, & Icier, 2013). Heterogeneous structure of meat samples affects the uniform heat distribution such as fat in meat product do not generate the heat at same rate as muscle (Shirsat, Lyng, Brunton, & McKenna, 2004). Such difficulties are encountered in applying ohmic treatment to meat and meat products.

In contrast, low temperature cooking can generally maintain high level of the nutritional values of the cooked products and is widely used in the food industry (Becker et al., 2016; Blahovec et al., 2015).

EFFECT OF COOKING METHODS ON QUALITY PARAMETER

Cooking of meat products is essential to achieve a palatable and safe product (Isleroglu, Kemerli, & Kaymak-Ertekin, 2015). Also, it may influence essential qualities identified with consumer's inclinations, as flavour and tenderness (Pietrasik, Dhanda, Pegg, & Shand, 2005). Cooking methods affects the nutritive values of meat. Generally, heat is applied to meat in different approaches to enhance its hygienic quality by inactivation of pathogenic microorganisms and to enhance its flavour and taste, and increase shelf life (Bognar, 1998; Pokorny, 1999). Meat nutritional values could be modified due to physicochemical reactions during cooking. Cooking instigates water loss in the food, expanding its lipid content, while some fat is lost (Garcıa-Arias, Pontes, Garcıa-Linares, Garcıa-Fernandez, & Sanchez-Muniz, 2003). Cooking reasons structural changes, which diminish the water holding capacity of the meat. Shrinkage on cooking causes the most noteworthy water loss at 60–70 °C and it is assumed that water is removed by the pressure applied by the shrinking connective tissue on the aqueous solution in the extracellular void (Tornberg, 2005).

Water debinding and migration in meat amid cooking are identified with the denaturation and contraction of protein structures created by expanding temperature (Lepetit, 2007; Palka & Daun, 1999; Tornberg, 2005). Tenderness is one of the most important quality attributes of meat

Effect on Cooking Loss

Cooking loss is a combination of liquid and soluble matters lost from the meat during cooking (Aaslyng, Bejerholm, Ertbjerg, Bertram, & Andersen, 2003; Soyer, Ertaş, & Üzümcüogˇlu, 2005). Cooking loss is a critical factor in meat industry as it determines the technological yield of the cooking process (Kondjoyan, Oillic, Portanguen, & Gros, 2013). From a nutritional perspective, cooking loss brought about loss of soluble proteins, vitamins and different supplements (Yarmand, Nikmaram, Emam Djomeh, & Homayouni, 2013). Cooking loss was calculated as the percent weight difference between fresh and cooked samples with respect to the weight of fresh meat samples (Chiavaro, Rinaldi, Vittadini, & Barbanti, 2009).

The cooking loss begins to develop around 40 °C. In meat with low pH (below 5.4 for pork), cooking loss begins as low as around 30 °C. The rate of cooking loss development is greatest between 50 °C and 70 °C and, after which it falls (Bejerholm & Aaslyng, 2004a). Total cooking losses rely on the temperature and rate of heating (Hearne, Penfield, & Goertz, 1978; Palka & Daun, 1999). Table 3 presented the effect of different cooking methods on meat cooking loss.

Table 3. Selected publications on cooking loss during meat cooking

Produce	Cooking method	Cooking conditions	Cooking loss	Reference
Turkey meat	Forced convection (dry air, RH - 8%), and	Oven cooking at 100 °C.	32.2%	(Mora, Curti, Vittadini, & Barbanti, 2011)
	Low steam (RH- 35%)		15.9%	
	High steam (RH - 88%)		22.8%	
Goat meat	Vacuum-packed plastic bags and retorted to the following internal temperatures	50°C	5.91 ± 2.54	(Liu, Meng, Gao, Li, Luo, & Dai, 2013)
		60°C	8.71 ± 2.95	
		70°C	15.38 ± 4.39	
		80°C	33.08 ± 4.86	
		90°C	41.25 ± 1.73	
Foal meat (internal temperature of 70 °C)	Roasting	200 °C/ 12 min	26.71 ± 3.51	(Domínguez, Gómez, Fonseca, & Lorenzo, 2014)
	Grilling	130–150 °C / 5 min	22.45 ± 5.51	
	Microwave	1000 W/ 1.5 min on each surface	32.49 ± 6.41	
	Frying	170–180 °C / 4 min on each surface	23.73 ± 2.87	
Beef	Oven cooking	200°C/ 15min	31%	(James & Yang, 2012)
	Sous vide	60°C/60min	19%	
	HPP	60°C/30min/ 150MPa	17%	
Beef	Sous vide	50°C /90min	8.33±1.71	(Vaudagna, et al., 2002)
		50°C/ 390 min	10.82 ± 1.62	
		65°C/ 90min	19.41±1.91	
Pork loin meat	Water bath	75°C (Cooking temperature)	35.7 ± 0.1	(Li, Sun, Han, & Yu, 2017)
	Steam stove		22.4 ± 1.5	
	Electric steamer		20.6 ± 1.4	
	Traditional nonvariable frequency microwave oven		28.0 ± 1.1	
	Inverter variable frequency microwave oven		21.3 ± 0.3%	
Pork loin chop	Pan frying	175°C/ 75s	11.26 ± 2.19	(Chunbao Li, Hu, Tang, Dong, Teng, Xu, et al., 2012)
		175°C/150 s	24.75 ± 3.00	
Muscovy drake meat	Pan frying	180°C/ 5min per side	43.36	(Omojola, Hammed, Attoh-Kotoku, Wogar, Iyanda, & Aremo, 2014)
	Deep frying	180°C/ 10 min	52.37	
	Gas grilling	200°C/ 10 min per side	44.40	
	Roasting	200°C/ 20 min	43.02	
Mutton chops	Grilling (Internal temperature)	51°C 65°C 71°C 79°C	5.5 12 16.5 31.4	(Sen, Naveena, Muthukumar, & Vaithiyanathan, 2014)
Pork	Ohmic heating Water bath	EPTs (60–100 °C)	9.71-30.22 22.53-38.51	(Dai, Zhang, Wang, Liu, Li, & Dai, 2014)
Whole turkey meat	Ohmic treatment Ohmic treatment Conventional treatment	LTLT (72 °C/15 min) HTST (95 °C/8 min) (72 °C end point temperature)	25.2 31.3 27.0	(Zell, Lyng, Cronin, & Morgan, 2010)
Meatball	Ohmically cooked (Centre temperature)	75 °C	15.57 ± 1.61	(Sengun, Yildiz Turp, Icier, Kendirci, & Kor, 2014)
Pork ham	Dry air cooking wet air cooking water cooking	120°C 82°C 82°C	22.25 12.74 9.73	(Cheng, Sun, & Scannell, 2005)

(Pathare & Roskilly, 2016)

Physical properties of meat and eating quality have been largely affected by cooking temperature and time (Christensen, Ertbjerg, Aaslyng, & Christensen, 2011). With increasing internal meat duck breast muscle temperature cooking loss gradually increased (Li, Wang, Dong, Xu, Gao, Zhou, et al., 2013). Many researcher reported the highest cooking loss for microwave cooking method (Domínguez, Gómez, Fonseca, & Lorenzo, 2014; El-Shimi, 1992; Janicki & Appledorf, 1974; Nikmaram, Yarmand, Emamjomeh, & Darehabi, 2011; Yarmand, Nikmaram, Emam Djomeh, & Homayouni, 2013). High electromagnetic field, high power and brief time related in microwaving came about protein denaturation, breaking down of the texture matrix, quick protein destruction brought on by heat shock to the proteins and, at long last, liberalization of a lot of water and fat (Yarmand & Homayouni, 2009). Cooking loss affected shear force values; samples with higher cooking loss percentages also presented the highest shear force values (Lorenzo, Cittadini, Munekata, & Domínguez, 2015).

Effect on Meat Textural Properties

Tenderness is one of the most important quality attributes of meat, which is significantly affected by different cooking methods and cooking duration. Consumer satisfaction has been influenced by meat tenderness (Silva, Torres Filho, Cazedey, Fontes, Ramos, & Ramos, 2015) and it is important to meet the meat tenderness that consumers demand. Most meat is eaten cooked, however, and the cooking process is one of the main determinants of tenderness (DeMan, 1976; Juárez, Aldai, López-Campos, Dugan, Uttaro, & Aalhus, 2012). Cooking has a major influence on the meat tenderness as the water- and fat-binding characteristics, and the texture, are closely related to the heating conditions applied (Pietrasik, Dhanda, Pegg, & Shand, 2005). Thermal changes that happen in muscle proteins amid heating and the development of another protein network directly affect product yield, texture, moistness, and general quality (Seideman & Durland, 1984). Thermal tenderness of meat after cooking specifically takes up with the net impact of this tenderisation and toughening, which relies on upon the cooking conditions (Li, et al., 2013).

Tenderness is thought to be the characteristic of eating quality which most impacts consumer acceptability (Boleman, Boleman, Miller, Taylor, Cross, Wheeler, et al., 1997; Delgado, Rubio, Iturbe, Méndez, Cassís, & Rosiles, 2005; Huffman, Miller, Hoover, Wu, Brittin, & Ramsey, 1996). The improvement of tenderness in meats is mainly caused by changes in structure of connective tissues solubilised by heat, while at the same time heat denaturation of myofibrillar proteins generally causes meat toughening (Palka & Daun, 1999). These heat-induced changes are time and temperature dependent, and the net effect of this toughening or tenderization relies on upon cooking conditions (Li, et al., 2013; Obuz, Dikeman, & Loughin, 2003).

Trained panel or physical methods used for meat tenderness determination. Warner–Bratzler shear force (WBSF) test has been widely used to estimate tenderness of raw and cooked meat as a standard mechanical measurement (Combes, Lepetit, Darche, & Lebas, 2004; Girard, Bruce, Basarab, Larsen, & Aalhus, 2012; Lorenzen, Calkins, Green, Miller, Morgan, & Wasser, 2010). The profile indicates either force applied over time or force applied versus the distance that the blade has travelled (Girard, Bruce, Basarab, Larsen, & Aalhus, 2012). However, there is a general lack of consistency or standards to choose and report a set of tenderness values even among researchers on the same type of meat.

James and Yang (2012) compared three cooking methods (conventional oven roasting, sous vide and high pressure processing) for their impact on toughness of bovine M. semitendinosus. The peak shear force of the beef expanded subsequent to cooking as the heat prompted denaturation of the myofibrillar and connective tissue proteins (Vaudagna, et al., 2002). Peak shear force was highest for the oven roasted beef (103N), then sous vide cooking (76N) and HPP treated beef was the lowest (54N).

Powell et al. (2000) showed that a slower cooking rate increased tenderness of dry roasted beef semitendinosus. Slower heating rate permits more opportunity for collagen solubilisation, consequently contributing more to meat tenderization than in meat cooked at higher heating rates. *However, sous vide* cooking shear force mean values decreased at higher temperature as the temperature increased (Vaudagna, et al., 2002).

Slower cooking methods shows the higher meat tenderness. Tenderness of meat should correlate with other quality parameter like colour and cooking loss. Future research should include the energy requirement for different cooking methods for consumer's preference for meat.

Effect on Meat Colour

Meat colour is one of the critical parameter characterizing the meat quality and influencing consumer's preference. It is thought to be an indicator of meat freshness and level of meat doneness (Mancini & Hunt, 2005). The HunterLab *L**, *a**, *b** and the modified CIE system called CIELAB colour scales were opponent-type systems commonly used for colour measurement (Karamucki, Gardzielewska, Rybarczyk, Jakubowska, & Natalczyk-Szymkowska, 2011; Pathare, Opara, & Al-Said, 2013). The parameter *a** takes positive values for reddish colours and negative values for the greenish ones, whereas *b** takes positive values for yellowish colours and negative values for the bluish ones. *L** is an approximate measurement of luminosity (Pathare, Opara, & Al-Said, 2013). Each colour parameter has a certain association with quality attributes, for example, the substance of fundamental compound parts in the meat, pH, and water holding capacity.

It is known that the myoglobin protein is the essential heme pigment accountable for meat colour. Colour estimation in cooked meat can give reliable information about eating quality characteristics (García-Segovia, Andrés-Bello, & Martínez-Monzó, 2007). Many consumers consider the colour of cooked meat as a reliable indicator of safety and doneness. Dull- brown interiors are viewed as a sign of a well-done item, though pink appearance is identified with uncooked meats (King & Whyte, 2006).

Colour opacity rises when the internal meat temperature is between 45 °C and 67 °C due to the denaturing of the meat proteins myosin and actin, which do not add to the red colour, overrides the red colour of myoglobin (Martens, Stabursvik, & Martens, 1982). Tornberg (2005) reported the increase in meat colour opacity at about 35 °C due to the denaturing of myosin. At 40 °C, most of the original myosin molecules have changed to monomers with merged myosin heads. Above 50 °C, myosin molecules are completely coagulated and the meat appears opaque (Tornberg, 2005). Heated samples has more colour brightness than raw samples. In roasted samples because of dark surface, brightness was reduced but more bright colours were found inside of the samples. Generally, the samples subsequent to heating because of pigment oxidization (heme group) become colourless (Nikmaram, Yarmand, Emamjomeh, & Darehabi, 2011). Ground beef colour appearance during cooking has been affected by interconverting system of three types of myoglobin and the debasement of them through oxygenation, oxidation and reduction reactions (Liu & Chen, 2001).

Ohmically cooking produces more homogenous colour inside of the ground beef while the crust layer in the surface of the ground beef could not have been achieved (Bozkurt & Icier, 2010b). There was an increment in hue angle values of cooked samples contrasting with raw sample. *In Sous vide* cooking, the hunter laboratory parameter *a** was strongly influenced by temperature, diminishing as the treatment temperature increased (Vaudagna, et al., 2002). In microwaved cooking, major and critical colour changes happen in short time (Nikmaram, Yarmand, Emamjomeh, & Darehabi, 2011).

Liu et al. (2013) reported that with increasing cooking temperature, meat had a tendency to be lighter because of an expanded reflection of light, emerging from light scattering by denatured protein. The redness decreased significantly when cooking temperature increased from 50°C to 80°C and remained at a very low value above 80°C. As myoglobin, the most heat stable sarcoplasmic proteins was totally denatured when meat was cooked to temperature above 80° C. Cooking temperature had influence on meat colour. It is important for consumers to select operating conditions for preferred colour meat.

Colour measurement in cooked meat can provide reliable information about eating quality attributes (García-Segovia et al., 2007). The myoglobin protein is the primary heme pigment responsible for meat colour, with different species contributing to colour changes during the cooking of meat (deoxymyoglobin, oxymyoglobin, sulfmyoglobin, metmyoglobin, etc.). The spectral features in the visible region allow us to explain these changes. During cooking, three forms of myoglobin interconvert and are degraded through oxygenation and oxidation and reduction reactions, ultimately influencing the appearance of meat colour (Liu & Chen, 2001). Visible reflectance spectral intensity variations likely indicate a dynamic conversion and decomposition for a number of myoglobin derivatives. Four bands around 445, 485, 560, and 635 nm are identified as DeoxyMb, MetMb, OxyMb, and sulfmyoglobin (SulfMb) spices, respectively. The colours of these spices are defined as purplish-red for DeoxyMb and cherry-red for OxyMb, while MetMb is brownish-red and finally SulfMb is green in colour (Liu et al., 2003).

Effect on Meat Shrinkage

Shrinkage during cooking often thought to be the poor meat quality indication by consumers. Degree of shrinkage is essential for the consumers as different thermal treatment causes undesirable changes in meat structure and increased shrinkage consider as low quality (Barbera & Tassone, 2006). Meat shrinkage has been determined by calculating the difference between the raw and cooked areas of meat sample. The change of linear dimensions, surface and volume due to cooking has been measured. It can investigate the relationship between meat water and shrinkage and utilized as a part of meat quality examination. Recently meat shrinkage has been measured on archiving the colour image of raw and cooked meat sample (Półtorak, Wyrwisz, Moczkowska, Marcinkowska-Lesiak, Stelmasiak, Rafalska, et al., 2015; Wyrwisz, Półtorak, Poławska, Pierzchała, Jóźwik, Zalewska, et al., 2012). However, manual shrinkage estimation is tedious and variable, as a result of its subjective nature.

According to Tornberg (2005) the shrinkage of meat can be summarized as: (1) the transverse shrinkage of the fibre begins at 35–40 °C, it happens mainly at 40–60°C and it broaden the gap between the fibres and their surrounding endomysium, (2) the shrinkage of the connective tissue begins at 60 °C, and at 60–70 °C the connective tissue network and the muscle fibres cooperatively shrink longitudinally. The application of low temperature and long treatments could minimise the shrinkage effect during thermal processing (Półtorak, et al., 2015). The level of shrinkage augmentations with the addition in temperature and causes large water loss during cooking (Tornberg, 2005)

Effect on Meat Juiciness

Meat juiciness is considered to arise out of moisture discharged by meat amid chewing, and moisture from saliva (Christensen, 1984; Howard, 1976). Moisture loss has the influence on juiciness, which can happen by evaporation in dry heat cookery and by exudation and diffusion in moist heat cookery (Hernández, Navarro, & Toldrá, 1999).

Cooking procedure and raw meat quality had the effect on juiciness of meat. However, to date, the only reliable and consistent measure of juiciness is accomplished using sensory methods (Winger and Hagyard 1999). As the complexity of juiciness also causes difficulties in performing objective measurements (Juárez, Aldai, López-Campos, Dugan, Uttaro, & Aalhus, 2012)

The core temperature greatly affects juiciness of meat (Aaslyng, Bejerholm, Ertbjerg, Bertram, & Andersen, 2003). An increase of the centre temperature lessens the juiciness (Bejerholm & Aaslyng, 2004b). Low oven temperature will give a more juicy meat contrasted with meat cooked at a higher oven temperature with the same centre temperature (Bejerholm & Aaslyng, 2004b). In beef cooking, juiciness and cooking loss are negatively correlated, implying that a high cooking loss results in low juiciness (Toscas, Shaw, & Beilken, 1999). Cooking loss has a great influence on the juiciness of meat.

ENERGY REQUIREMENT FOR MEAT COOKING

Cooking is an important part of daily food preparation in commercial and residential settings. Energy requirement for cooking can be prodigious and energy varies with different cooking methods. There are very limited studies in literature focused on the energy consumption for meat cooking. Suwannakam et al. (2014) investigated the energy consumption of the combination of far-infrared and superheated steam with forced air (FIR-SS-FA) system, a combination of far-infrared and superheated steam (FIR-SS) system, and a combination of forced air and superheated steam (FA-SS) system for roasting skinless deboned chicken breast meat. FIR-SS-FA system showed the lowest specific energy consumption (2.54 kWh/kg), which has the shortest cooking time also. The specific energy consumption (SEC) was obtained from the input electrical energy and the quantity of meat samples used:

$$SEC = \frac{Input\ \ electrical\ \ energy\left(kW - h\right)}{Weight\ \ of\ \ sample\left(kg\right)}$$

De Halleux et al. (2005) used ohmic heating to cook Bologna ham and found 211 and 252 kJ/kg energy requirement. However, for conventional smoke cooking of Bologna ham required higher energy 1200 and 8100 kJ/kg compared to ohmic heating. (Reichert and Thumel 1986; Singh 1986; Reichert, 1991).

Laycock et al. (2003) used radio frequency cooking (RF) and water bath (WB) cooking for beef cooking. RF cooking is much more energy efficient than water bath cooking of beef cooking. WB cooking showed the low efficiency as it uses large amount of water to cook small amount of meat product and the large heat losses to environment.

Jouquand et al. (2015) compared the microwave cooking with traditional cooking for beef burgundy cooking. Microwave cooking (4.67 kWh) showed lower energy consumption than traditional cooking (6.52 kWh). Cooking time has been reduced by 56% compared to traditional cooking. There are higher energy losses in traditional cooking.

Payton and Baldwin (1985) compared microwave-convection, forced-air convention and conventional electric oven for beef steak cooking. Microwave-convection oven utilises microwaves as well as forced convection heat. Microwave-convection oven required less cooking time and total cooking energy. Generally, microwaveable food is more energy efficient during cooking stages because the energy heats only the food, not the whole oven compartment. The volume of fluid or mass of food produce affected the microwave cooking energy efficiency. Compared with the conventional cooking, microwave cooking reduces the energy consumption as well as reduces the cooking time (Chang, Xu, Li, Huang, Liu, & Zhou, 2011).

De et al. (2014) developed energy-efficient cooking techniques for goat meat cooking. Pressure cooker contains the meat (1 kg) and water (0.3 litre) has been kept on the stove till the time (ti) upto to hear the first whistle. Immediately pressure cooker removed from the stove and kept in the closed insulated box for 30 minutes for cooking to use the stored heat in the meat. This method reported the considerable fuel energy saving and on stove time (19.25 min) compared to conventional cooking (40.51 min) applied in domestic cooking. Energy efficiency of cooking goat meat with this method is calculated to be 87% compared to 41% with conventional method of using pressure cooker. However the authors did not conducted quality analysis for the cooked meat.

Similarly, Oberascher, Stamminger, and Pakula (2011) demonstrated that there is a negative linear relationship between increasing water volume and the specific energy consumption (or energy per volume of water) to heat water to 90 °C under a variety of conditions (electric kettle, pots, microwave, etc.). Since water-boiling efficiency increases with pan size and volume of fluid, encouraging consumers to cook food in larger volumes, when possible, would reduce the amount of cooking energy required per mass of cooked food (J/kg food).

Other Factor Affecting Energy Consumption

Cooking is globally essential for food safety and decreases the energy utilization amid cooking may affect worldwide energy demands. Residential cooking can require significant amounts of energy—approximately 7 MJ/ kg food product (Dutilh & Kramer, 2000). The factors affecting the energy consumption includes not only cooking process but also the production and transport efficiency of fuel sources, the appliance end use efficiency and consumer behaviour during cooking. The composition, size and shape of the cookware has the impact on energy consumption.

Energy saving behaviours that consumers can perform during cooking includes reduce the length of the period of use, match sizes, volumes and amount of heat to the food for preparation. Selection of an appliance which consumes less energy or a non-energy-consuming device or method also useful for energy saving (Wood & Newborough, 2007). Study in the UK showed that the information on energy saving practices and supplying real time energy consumption meter display could reduce the cooking energy usage up to 20% (Wood & Newborough, 2003).

Cooking is a universal and indispensable process for meat and other fresh product consumption as well as food safety. Thus, implementing policies/practices that lessen energy utilisation amid cooking will significant affect worldwide energy demands. Most of the GHG discharges are identified with home processing, especially to energy use for cooking; which represented between 50% and 70% of overall GHG emissions (Edwards-Jones, Plassmann, York, Hounsome, Jones, & Milà i Canals, 2009). Therefore, more efficient meat cooking methods would achieve reductions in energy use and reduce the carbon footprints of food production.

Alternative energy source such as biomass, solar may reduce energy uses for meat cooking. The use of wood as cooking fuel (fuel-wood) in order to meet the cooking energy requirement, due to high cost of alternative energy source results in deforestation and adverse environmental effects. Hence, there is the need for more research to develop low cost and environmentally friendly alternatives such biogas cooker and solar cookers, utilizes renewable energy sources that would diminish the dependence on traditional fuels. It could help in conservation of conventional fuels in developing countries and electricity/gas in the developed areas.

In meat cooking, it is important to increase the use of energy from renewable sources, together with energy saving and increased energy efficiency to reduce GHG emissions. Future research should focus on redesigning and improving meat cooking processes. Cooking energy demand should be optimized by improving real time cooking data and benchmarking can identify the opportunities to reduce demand.

CONCLUDING REMARK

The meat production for years has been considered a very energy intensive sector. But, with the advent of novel emergent thermal and non-thermal technologies the meat businesses have now the potential to be energy efficient and at the same time produce safe and quality products. However, application of some of the mentioned technologies needs high infrastructure investments, control of various parameters related to the technology and its legal approvability. These reasons have inhibited its wider acceptability, but it is slowly picking pace and replacing traditional energy intensive processes and practices. In future, due to rising energy prices and environmental regulations, there is tremendous pressure on meat sector to be energy-efficient and less dependent on non-renewable energy sources. And, this can only be achieved through the adoption of novel emergent thermal and non-thermal technologies. Energy efficient technologies can play an important role in ensuring a more resilient meat processing and satisfying consumer demands and needs.

Meat cooking methods play a major role on eating quality attributes. It is important to focus more on evaluating the optimum cooking process for high quality and energy efficient meat cooking. Energy efficiency or energy required for cooking is very important area to emphasis as limited studied focused on energy consumption. It is important to focus the study, which correlate the meat quality and consumer's preference related to meat cooking.

Renewable/sustainable energy can be used for meat cooking. As energy efficient cooking is not always the consumer's eating preference. It is important to investigate energy efficient cooking technique to conserve most extreme energy amid cooking and to secure meat quality parameter. In addition, dialogue and education to consumers is needed to reduce energy consumption without compromising the quality meat products.

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