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REVIEW ARTICLE

Quality and Energy Evaluation in Meat Cooking

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Abstract Consumer acceptance of meat is strongly influenced by the eating quality. Cooking method has great impact on eating quality of meat, and energy consumption is important parameter to consider while selecting the cooking method. Energy requirement for well-cooked meats varies with cooking method, appliances and consumer behaviour. Energy consumption reduction during meat cooking may have the influence on global energy requirement. This article critically reviewed the effects on quality characteristics of meat and meat products by different cooking methods. The different cooking methods including oven, frying, sous vide and ohmic cooking are discussed in detail, and their effects on meat quality parameters such as colour, tenderness, cooking loss, shrinkage and juiciness are also presented. Highlighting on the role of cooking process on meat quality, energy requirement for cooking were identified.

Keywords Meat cooking · Tenderness · Cooking loss · Thermal diffusivity · Cooking energy

Introduction

Meat is a basic portion of sound and all-round balanced diet due to its nutritional richness. Meat is a valuable wellspring of high natural quality protein and also other B complex vitamins, zinc, selenium, iron, vitamin B12 and phosphorus [92]. Offal meats like liver are also vital sources of vitamin A and folic acid [9]. Meat is a complex food with a structured nutritional composition [8].

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 also has an important effect on the nutritional properties and same time on its possible toxicity [62]. With cooking meat becomes edible and more digestible [8]. Generally, consumer chooses a cooking method that produces a high-quality meat products having favourable texture and taste [61]. The United States Department of Agriculture (USDA) recommended the internal temperature for different meat such as 62.8 °C for steaks, roasts and fish, 71.1 °C for pork and ground beef, 76.7 °C for chicken breasts and 82 °C for whole chicken [61]. Physical properties and eating quality of meat are affected by cooking temperature and time. During cooking, the distinctive meat proteins are denatured and this reasons structural changes in the meat textural profile. These resulted in destruction of cell membranes, shrinkage of meat fibres, the aggregation and gel formation of myofibrillar and sarcoplasmic proteins, and shrinkage and solubilization of the connective tissue [119]. Heat treatment can result to undesirable meat quality changes, such as nutritive value loss because of lipid oxidation and changes in a few segments of the protein fraction. [101].

Cooking consumes large amount of energy and releases lots of greenhouse gas (GHG) emissions [131]. Selection of cooking method, fuel and cookware are beneficial for reducing the carbon footprint of the cooking unit. Furthermore, the correct use and improved performance of cookware could decrease emissions of all the pollutants per unit of useful heat. The meat structure, size and state of the cookware had impact on energy utilization. Consumer's behaviours also have big influence on energy demand

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during cooking. Cooking energy demand increases up to two times if consumers are not aware of energy-saving techniques during cooking [43].

The purpose of this review is to provide an overview of different cooking methods on meat quality parameters and the impact on energy requirement. The effects of meat cooking on thermal properties and quality characteristics, such as tenderness, juiciness and shrinkage are discussed. In addition, it is important to inform the consumers how to properly handle and cook energy-efficient meat products.

Meat Cooking: An Overview

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. [6]. Distinctive heat transfer media has been utilized for meat cooking which incorporates dry heat methods, moist heat methods or microwave cooking. 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 cooking methods commonly used for meat preparation are discussed below.

Oven Cooking

Oven cooking is broadly utilized in commercial processing and foodservice operations [76]. Quality attributes and microbial safety of products have been affected by oven cooking or roasting [42]. 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. [87]. The reduction in total cooking loss is important as meat promotes higher solubilization of intramuscular collagen-based connective tissue leading towards tenderization due to high water-holding capacity. 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 [4].

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 [78]. 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 [20]. 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 have 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 [124]. Murphy et al. [78] 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 [100].

Mora et al. [76] compared forced convection (dry air, RH = 8 %), low steam (RH = 35 %) and high steam (RH = 88 %) oven cooking at 100 °C for turkey meat cooking. Low steam cooking enhanced quality of turkey meat and lessened water utilization, and it should be consider as an alternative to steam saturation cooking.

Frying

Frying is a cooking technique where fat or oil is utilized as the heat transfer medium, in direct contact with the food [122]. 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 [74].

Immersing frying can be characterized by four stages [38]. During the first stage, heat transfer is by convection and food surface heats up to the boiling point of water. Surface water starts to boil and evaporate in the second stage. Therefore, heat transfer between the oil and the food changes from natural convection to forced convection because of turbulence in the oil. This enhances the heat transfer coefficient. Dehydration of surface and high temperature reason crust layer formation in this stage. In the third stage, temperature in the inward area of the food builds gradually to boiling point of water. Physicochemical changes like starch gelatinization and protein denaturation happen in this stage. Also, crust layer thickness expands and water vapour transfer at the surface lessens. At the last stage, surface evaporation stops and no air pockets are seen on the surface of the food [2].

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 [123]. The technique is also known as the "cook-in-bag" system. 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 maintained the lower temperature, which minimizes the temperature gradient and reduces the damage to heat sensitive proteins and supplements. It also reduces cooking loss and preserves the juiciness [31, 123]. Low temperature in sous vide method has a positive effect on meat tenderness. And the extended cooking time builds collagen solubility [6]. In sous vide cooking, the tenderization of the connective tissue takes place through the solubilization of the intramuscular collagen inside the moist in-pack environment [40, 47]. Sous vide cooking is promoted for its ability to retain nutrients, enhance flavour and texture in a manner that conventional roasting can not deliver [77].

Vaudagna et al. [123] used sous vide method for beef muscles cooking by applying different low temperature with long time treatments. Higher cooking loss and lower shear force values have been found when the temperature increased from 50 to 65 °C. There were no significant effect of the processing times (90–360 min) on cooking loss and shear force. The colour parameter *a** value decreased as processing temperature increased. García-Segovia et al. [40] also reported the similar observation.

High-Pressure Processing

High-pressure processing (HPP), also known as high hydrostatic pressure (HHP) treatment, is used by the food industry for microbial inactivation coupled with preservation of food quality [27, 50, 60]. High-pressure processing induces meat protein modifications differently than heat-induced changes [111].

HPP treatment has created diverse textures on food with minimal effects on flavour, colour and nutrient stability [116, 121]. HPP increases the solubility of myofibrillar proteins as a consequence of depolymerization of protein molecules, which improves gelation and meat tenderness [18, 116]. Pressure is highly effective in accomplishing desirable tenderization of myofibrillar proteins, and it has little impact on the intramuscular collagen in the connective tissue that are settled by hydrogen bonds [116]. Mor-Mur and Yuste [75] reported that the high-pressure treatment (500 MPa and 65 °C) of cooked sausages produces less firm, more cohesive products with less weight loss compared to heat-pasteurized sausages cooked at 80–85 °C for 40 min.

Ohmic Heating

Ohmic heating is an electro-heating technique. It involves the utilization of the electricity to a food material, bringing about volumetric heat generation [115]. The system depends on the entry of electrical current through a food item that has electrical resistance [51]. Electrical energy is converted into the heat, and the heat generation relies on the voltage gradient and electrical conductivity [103]. And it resulted in efficient rising in internal temperature of food [125].

Ohmic cooking in meat products resulted in faster cooking, less power consumption and safer product [86]. Ohmically cooking produces a firmer sample than conventional cooking [14]. Ohmic heating resulted in cooking loss reduction and improved juiciness [135]. 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 [13, 14, 52, 86, 108, 135]. However, ohmic cooking is an inefficient cooking method for desirable changes in surface colour and texture in meat products [13, 14, 134]. 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 [109]. Such difficulties are encountered in applying ohmic treatment to meat and meat products.

Zell et al. [135] used ohmic heating and steam cooking for whole beef muscle. Ohmically cooked meat had a significantly uniform lighter and less red colour, and less cooking loss but tougher texture compared to steam-cooked meat.

Effect on Different Quality Parameter

Cooking of meat plays a vital role to achieve a palatable and safe product [119]. Also, it may influence essential qualities identified with consumer's inclinations, as flavour and tenderness [93]. Cooking methods affect 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 [11, 94]. 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 [39]. 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 [119].

Water debinding and migration in meat amid cooking are identified with the denaturation and contraction of protein structures created by expanding temperature [65, 87, 119]. There is up to 80 % water loss from beef burger during pan frying [84]. The effect of different cooking methods on meat quality parameter is discussed below.

Effect on Cooking Loss

Cooking loss is a combination of liquid and soluble matters lost from the meat during cooking [1, 114]. Cooking loss is a critical factor in meat industry as it determines the technological yield of the cooking process [63]. From a nutritional perspective, cooking loss brought about loss of soluble proteins, vitamins and different supplements [133]. Cooking loss was calculated as the per cent weight difference between fresh and cooked samples with respect to the weight of fresh meat samples [20].

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 and 70 °C and after which it falls [6].

Total cooking losses rely on the temperature and rate of heating [45, 87]. Table 1 presented the effect of different cooking methods on meat cooking loss.

Physical properties of meat and eating quality have been largely affected by cooking temperature and time [22]. With increasing internal meat duck breast muscle temperature, cooking loss gradually increased [67].

Domínguez et al. [34] studied the effect of four different cooking methods (roasting, grilling, microwaving and frying) on cooking loss of foal meat. Microwave cooking resulted in the highest cooking loss, which were in agreement with other researchers [37, 55, 80, 133]. 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 [132].

Effect on Meat Textural Properties

Tenderness is a textural property which is considered to be the most critical attribute in meat consumption [30, 126]. Consumer satisfaction has been influenced by meat tenderness [110], and it is important to meet the meat tenderness that consumers demand.

Most meat is eaten cooked, and the cooking process is one of the main determinants of tenderness [29, 57]. 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 [93]. 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 [104]. Thermal tenderness of meat after cooking specifically takes up with the net impact of this tenderization and toughening, which relies on upon the cooking conditions [67].

Changes in texture of meat amid cooking are because of the heat-induced structural changes joined with enzymatic breakdown of the proteins. The impact of the time/temperature element and the core temperature relies on the piece of the meat. Tenderness is thought to be the characteristic of eating quality which most impacts consumer acceptability [12, 28, 49]. Heat solubilizes collagen that result in tenderization, though warmth denatures myofibrillar proteins that result in toughening. These heat-induced changes are time and temperature dependent, and the net effect of this toughening or tenderization relies on upon cooking conditions [67, 81].

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 [23, 41, 70]. The profile indicates either force applied over time or force applied versus the distance that the blade has travelled [41]. Usually, the most considered parameter of the curve is the maximum shear force. Destefanis et al. [30] classified meat into five groups according to their tenderness, namely very tender ($WBSF < 32.96$ N), tender ($32.96 \text{ N} < WBSF < 42.77$ N), acceptably tender ($42.87 \text{ N} < WBSF < 52.68$ N), hard ($52.78 \text{ N} < WBSF < 62.59$ N) and very hard ($WBSF > 62.59$ N). 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.

Shear force was taken as an hardness indicator and reported to give more data on the degree of denaturation of the myofibrillar proteins (primarily actomyosin complex) that brought about shrinkage of the muscle fibres, in comparison with alterations of connective tissue component (i.e. collagen shrinkage and gelatinization) after cooking of meat [44, 45]. Cooking of pork brought on an increment in the force expected to cut the meat demonstrating an increase in hardness (i.e. reduction in tenderness) [20].

James and Yang [54] compared three cooking methods (conventional oven roasting, sous vide and high-pressure

Table 1 Selected publications on cooking loss during meat cooking

Produce	Cooking method	Cooking conditions	Cooking loss	References
Turkey meat	Forced convection (dry air, RH-8 %)	Oven cooking at 100 °C	32.2 %	[76]
	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	[68]
		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	[34]
	Grilling	130–150 °C/5 min	22.45 ± 5.51	
	Microwaving	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/15 min	31 %	[54]
	Sous vide	60 °C/60 min	19 %	
	HPP	60 °C/30 min/150 MPa	17 %	
Beef	Sous vide	50 °C/90 min	8.33 ± 1.71	[123]
		50 °C/390 min	10.82 ± 1.62	
		65 °C/90 min	19.41 ± 1.91	
Pork lion chop	Pan frying	175 °C/75 s	11.26 ± 2.19	[66]
		175 °C/150 s	24.75 ± 3.00	
Muscovy drake meat	Pan frying	180 °C/5 min per side	43.36	[83]
	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	5.5	[105]
		65 °C	12	
		71 °C	16.5	
		79 °C	31.4	
Pork	Ohmic heating	EPTs (60–100 °C)	9.71–30.22	[24]
	Water bath		22.53–38.51	
Whole turkey meat	Ohmic treatment	LTLT (72 °C/15 min)	25.2	[136]
	Ohmic treatment	HTST (95 °C/8 min)	31.3	
	Conventional treatment	(72 °C end point temperature)	27.0	
Meatball	Ohmically cooked (centre temperature)	75 °C	15.57 ± 1.61	[106]
Pork ham	Dry air cooking	120 °C	22.25	[19]
	Wet air cooking	82 °C	12.74	
	Water cooking	82 °C	9.73	

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 [123]. Peak shear force was highest for the oven-roasted beef (103 N), followed by sous vide cooking (76 N) and HPP-treated beef (54 N).

Powell et al. [96] showed that a slower cooking rate increased tenderness of dry roasted beef semitendinosus. Slower heating rate permits more opportunity for collagen solubilization, 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 [123].

Liu et al. [68] reported a two-phase increase on shear force of goat meat. The first increase arises between 50 and 55 °C and the second increase between 70 and 75 °C. These occurred due to the changes in sarcoplasmic protein, myofibrillar protein and collagen solubility during cooking. The first increment in shear force is expected because of the expanded strength of the perimysial connective tissue brought about by its straightening out of the crimped collagen fibres. The second increment could be created by the expanded strength of the single muscle fibres in light of the denaturation of proteins and interaction between myofibrillar and connective tissues [23]. Then again, the cooking loss expanded around 70 and 75 °C brought about higher meat toughness [23, 87].

Slower cooking methods show 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.

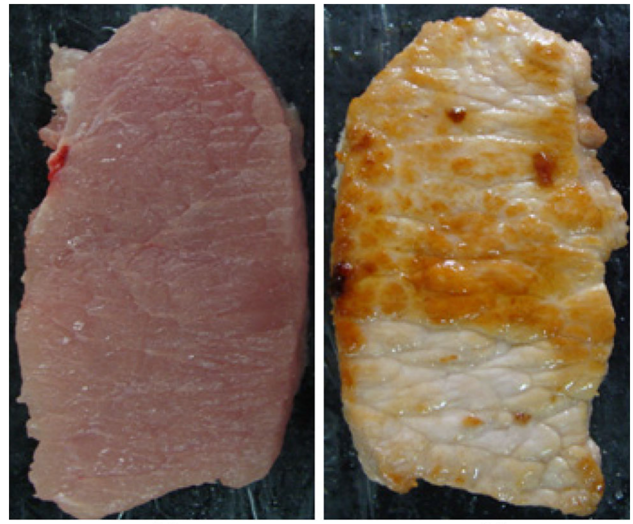

Fig. 1 Meat colour change and crust formation during frying [66]. **a** Raw meat, **b** colour change and crust formation

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 [71]. The HunterLab L^*, a^*, b^* and the modified CIE system called CIELAB colour scales were opponent-type systems commonly used for colour measurement [58, 90]. 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 [90]. 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 haeme pigment accountable for meat colour. Colour estimation in cooked meat can give reliable information about eating quality characteristics [40]. 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 [61]. Figure 1 showed the meat colour change and crust formation during frying.

Colour opacity rises when the internal meat temperature is between 45 and 67 °C as the denaturing of the meat proteins myosin and actin, which do not add to the red colour, overrides the red colour of myoglobin [73]. Tornberg [119] 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 [119]. Heated samples have 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 (haeme group) become colourless [80]. 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 [69].

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 [14]. 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 [123]. In microwave cooking, major and critical colour changes happen in short time [80].

Liu et al. [68] 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 to 80 °C and remained at a very low value above 80 °C. As myoglobin, the most heat-stable sarcoplasmic proteins were 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.

Effect on Meat Shrinkage

Shrinkage during cooking is 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 [5]. 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 have been measured. The relationship between meat water and shrinkage can be investigated 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 [95, 130]. However, manual shrinkage estimation is tedious and variable, as a result of its subjective nature.

According to [119], 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 minimize the shrinkage effect during thermal processing [95]. The level of shrinkage augments with the addition in temperature and causes large water loss during cooking [119].

Meat shrinkage plays a key role in the water transport during cooking. Considerable shrinkage of meat 7–19 % on area basis [119] and 11–20.3 % on diameter basis [85] was observed. Similarly, [88] reported the diameter shrinkage varied from about 20.8 % at 160 °C to about 23.5 % at 200 °C for fried hamburgers with a fat content of 20 %.

Effect on Meat Juiciness

Meat juiciness is considered to arise out of moisture discharged by meat amid chewing, and moisture from saliva [21, 48]. 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 [46].

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 [127]. The complexity of juiciness also causes difficulties in performing objective measurements [57].

The core temperature greatly affects juiciness of meat [1]. An increase of the centre temperature lessens the juiciness [7]. Low oven temperature will give a more juicy meat contrasted with meat cooked at a higher oven temperature with the same centre temperature [7]. In beef cooking, juiciness and cooking loss are negatively correlated, implying that a high cooking loss results in low juiciness [120]. Cooking loss has a great influence on the juiciness of meat.

Heat and Mass Transfer During Meat Cooking

Heat and mass transfer in meat products is a complex phenomenon affected by multiple physics involving energy transport, mass transport, fluid flow dynamics and mechanical deformation [16]. Differences in temperature and moisture levels between the air and the product can cause moisture evaporation from the product surface. As the product surface dries, internal moisture transport towards the product surface can occur [16]. Meat cooking environments are diverse and cooking conditions may vary over time. Hence, heat and mass transfer rates are influenced by multiple parameters including oven temperature, product load, airflow velocity, type of heating medium, and type of products (e.g. shape, dimensions, and thermal properties).

In the last two decades, computer modelling of heat transfer has gained special attention in the meat industry as it is a practical resource to estimate meat safety quantitatively. Bisceglia et al. [10] evaluated the temperature and water content dependency on cooking process time of meat samples. Finite elements software COMSOL multiphysics was used to simulate the process, and the model predicted transient temperature and moisture distributions inside the sample and transient cooking yield of meat samples during cooking was also predicted. Obuz et al. [82] developed a mathematical model to predict temperature and mass transfer of cylindrical beef roasts cooked in a forced air convection oven. The model predicted the cooking time with high accuracy.

Studies have shown that modelling of heat and mass transfer of meat products under cooking environments is a challenging task. One of the limitations of modelling cooking is that the thermal properties to great extent rely on processing and sample temperature, meat composition, component distribution and, finally, previous treatments [118]. Recently, Papasidero et al. [89] developed a computational model to correlate temperature, time and weight loss for a piece of meat cooked in oven. The model showed the good agreement with experiments.

Moisture diffusivity is an important transport parameter required for the analysis, design and optimization of all the processes that involve internal moisture movement. Moisture diffusivity (D) in the meat matrix is commonly taken from reported values. Table 2 presented the published data on moisture diffusivity during meat cooking.

Thermal Diffusivity

For heat transfer analysis, the information on thermo-physical properties and that on their variations is vital [53], and to estimate cooking time, product final temperature and cooking performances [100]. Thermal diffusivity includes the effects of properties like mass density, thermal conductivity and specific heat capacity. Thermal diffusivity, which is involved in all unsteady heat conduction problems, is a property of the solid object. The physical significance of thermal diffusivity is associated with the diffusion of heat into the medium during changes of temperature with time. The higher thermal diffusivity coefficient implies the quicker penetration of the heat into the medium and the less time required to expel the heat from the solid [32]. The higher thermal diffusivity values will result in more effective heat transfer.

Thermal diffusivity depends on the thermodynamics properties of material and its internal structure. Thermal diffusivity may be affected by different mechanisms of heat and mass transfer amid cooking of meat products. Physical and chemical changes due to thermal treatment prompt changes in the material structure [72]. Table 3 presented the thermal diffusivity data during cooking.

Energy Requirement for Meat Cooking

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. Recently, Suwannakam et al. [117] 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 force 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:

$$\mathrm{SEC} = \frac{\text{Input electical energy (kWh)}}{\text{Weight of sample (kg)}}$$

De Halleux et al. [26] used ohmic heating to cook Bolonga 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 [97, 98, 112].

Laycock et al. [64] used radio frequency cooking (RF) and water bath cooking for beef cooking. Radio frequency (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. [56] 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 [91] compared microwave convection, forced air convention and conventional electric oven for beef steak cooking. Microwave convection oven utilizes 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 [17].

De et al. [25] developed energy-efficient cooking techniques for goat meat cooking. Pressure cooker contains the meat (1 kg), and water (0.3 L) has been kept on the stove till the time (ti) to hear the first whistle. Immediately

Table 2 Selected publications on moisture diffusivity for meat cooking

Produce	Cooking method	Cooking condition	Moisture diffusivity (10^{-10} m^2/s)	Activation energy (kJ/mol)	References
Chicken meat	Frying	170–190 °C/15 min	36.50–74.20	20.00	[59]
Chicken nuggets	Deep frying	150–190 °C/1–4 min	20.93–29.32	8.04	[79]
Chicken nuggets	Oven baked	200–240 °C/5–25 min	1.90–3.16	25.70	[79]
Pork meat	Frying	90–110 °C	15.00–302.00	–	[113]
Pork slice	Superheated steam	140 °C/30 min	3.31–2.47 (seasoned pork)	11.59	[102]
			4.20–15.06 (unseasoned pork)	11.99	

Table 3 Thermal diffusivity during meat cooking

Produce	Cooking method	Thermal diffusivity (10^{-7} m^2/s)	References
Ground beef	Infrared radiation heating	1.82–1.62	[107]
Beef meatballs	Deep-fat frying	1.33	[3]
Pork meat	Frying (90, 100 and 110 °C)	1.12–1.83	[113]
Sausages	Frying	3.85	[33]
Mortadella bologna	Oven (80, 90 and 100 °C)	1.38–1.45	[99]
Mortadella	Oven cooking	2.40	[15]
Lyoner type sausages	Hot water cooking	1.35–1.52	[72]

pressure cooker is removed from the stove and kept in the closed insulated box for 30 min 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 conduct quality analysis for the cooked meat.

Other Factor Affecting Energy Consumption

Cooking is globally essential for food safety and decreases the energy utilization amid affecting worldwide energy demands. Residential cooking can require significant amounts of energy—approximately 7 MJ/kg food product [35]. The factors affecting the energy consumption include 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 have the impact on energy consumption.

Energy-saving behaviours that consumers can perform during cooking includes reduced 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 is also useful for energy saving [129]. 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 % [128].

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 utilization amid cooking will significantly 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 [36]. Therefore, more efficient meat cooking methods would achieve reductions in energy use and reduce the carbon footprints of food production.

Alternative sources such as biomass and solar energy 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 and utilize 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 efficient cooking methods 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.

Conclusions

Comprehensive review of literature showed that cooking methods play a major role in eating quality attributes. Selection of operating conditions not only affected the meat quality but also the efficiency of the applied cooking process. Improvement of the current cooking practices or investigating new cooking strategies is essential for the meat processing industry. Therefore, research should focus more on evaluating the optimum cooking process for high-quality and energy-efficient meat cooking. This will enable the consumer's to make proper selection cooking methods and processing parameter of meat cooking. Furthermore, research on cooking technology applicable in reducing energy requirement for cooking for commercial and domestic purposes should be emphasized.

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 consumers preference related to meat cooking. This includes the energy for different cooking processes. There are many studies on meat quality; however, energy consumption is also main requirement. Innovative methods like microwave cooking reduce the energy requirement compared to traditional cooking that causes higher cooking losses. It is important that these parameters should be optimized for energy-efficient quality meat cooking process.

Renewable 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 are needed to reduce energy consumption without compromising the quality meat products.

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