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Principle of Meat Aroma Flavors and Future Prospect

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1. Introduction

The population growth fact of the world has been much quickly increasing through the years. As reported by the United Nations Population Fund (UNFPA) the estimated world population of 6.1 billion in the year 2000 and reached to 7 billion in the year 2011, increased 0.9 billion people only after 10 years. The population increases always proportionally accompany to the consumption demands in which including foods. Calculating the global meat consumption only and based on the data collected from IFPRI/ FAO/ILRI by Delgado et al (1999) [1] suggested that global production and consumption of meat will continue to raise from 233 million metric tons in the year 2000 to 300 million metric tons in 2020. On the other hand, income growth of people in most of the countries especially in the developed countries has been significantly increasing in the recent years. Combination of the large populations together with a high-income that will give a big pressure for the food producers in general and meat producers in particular. As a consequence, higher income growth in countries has led to an increase in living standards and changes in consumer diets to include a higher proportion of meat and meat products. While, productivity and provision of meats on the markets has been limited and rising costs of production resulting in not keeping pace with the strong growth in demand, that has caused a rise in meat prices.

Although, a strong demand for meat amounts but consumers are getting quite fastidious to choose meat and meat products since consumer's preference for meat buying is strongly based on quality, freshness and hygiene. Quality factors are very important in the meat purchasing behavior of consumers including marbling (intramuscular fat tissues), texture, color, tenderness and especially flavor characteristics.

Aroma flavor characteristics of cooked meat in particular play the most important level in eating quality of meat, acceptance and preference by consumers. The aroma flavor charac-

teristics of cooked meats are derived from volatile flavor components which derive from thermally induced reactions occurring during heating via the four pathways including (1) Maillard reaction of amino acid or peptides with reducing sugars, (2) Lipid oxidation, (3) interaction between Maillard reaction products with lipid-oxidized products and (4) vitamin degradation during cooking [2]. Aroma flavor is perceived through the nostrils (orthonasal aroma) it gives the first impression of a certain food. When the food is placed in the mouth, the volatile flavor compounds will be transferred through the pharynx to the olfactory receptors (retronasal aroma). It has been reported that flavors together with other sensory attributes such as tenderness and juiciness are specially considered the most important criterion of acceptability and the palatability of meat that affects consumer's purchasing decisions [3,4]. It has been well known that all volatile flavor components are organic and they have low molecular weight [5]. The chemical structures of volatile flavor classes are varied widely including aldehydes, ketones, hydrocarbons, pyrazines, acids, esters, alcohols, nitrogen and sulfur-containing compounds and other heterocyclic compounds as well. Due to the differences in chemical structures therefore their volatility is also quite different.

Many factors have been found to be as influences on the aroma flavors of cooked meat. Rabe et al (2003) [6] found that among all food constituents, lipids generally have the greatest influence on production of aroma flavor components, as they not only reduce the vapour pressure of most flavor compounds. Otherwise, Kinsella (1990) [7] showed that aroma compounds are more lipophilic than hydrophilic therefore fats act as a solvents for aroma compounds reducing their volatility. In addition to these effects, other factors such as diets, breed, sex, chiller ageing, meat pH, cooking conditions which all also affect the flavor [8, 9, 40, 11]

With the crucial importance of aroma flavor of meat for the acceptance and preference of consumers and as well as the factors influencing the generation of aroma flavor compounds as mentioned above, the present chapter aims to highlight the basic information regarding aroma flavor components in terms of mechanisms of formation pathways; current techniques being used for detection; factors that affect aroma flavors; and final ideas and as well as suggestions are also given out to improve flavor quality attributes according to criterion of acceptability, satisfaction and the palatability for consumer.

2. Meat aroma flavor

2.1. The importance of volatile flavor compounds in contributing to the flavor characteristics of cooked meat

Flavor characteristics of cooked meat are directly detected by the nose (i.e., olfactory receptors) before and during chewing. Raw meat has little aroma and only blood-like taste, meat develops its aroma flavor characteristics during cooking as the result of complex interaction of precursors derived from both the lean and fat compositions of meat generating volatile flavor compounds that contribute to meat flavor [12]. To date, approximately thousands of volatile flavor compounds have been detected and identified in cooked meat. There is a large number of these compounds contributing to the flavor characteristics of cooked meat have been identified in previous works [13, 14, 15, 16, 17, 18, 19].

As mentioned above, regarding the chemical structures of volatile flavor classes, among that the heterocyclic compounds especially those containing sulfur are the important flavor compounds produced in the Maillard reaction providing savory, meaty, roasty and boiled flavor characteristics. While, lipid-degraded- compounds which give 'fatty' aromas to cooked meat and compounds which determine some of the aroma flavor differences between meats from different species [20]. The individual volatile compounds have been found to determine distinct aroma flavors of cooked meat represent; dimethylsulfide, 2-butanone, ethyl acetate, 2- and 3-methylbutanal, 2-heptanone, dimethyl trisulphide and nonanal were detected as key flavor compounds of cooked Irish Angus beef, while methional, 2,4-nonadienal and bezothiazole were characterized as meaty, oily notes in cooked Belgian Blue, Limousin and Aberdeen Angus beefs [21]. Kerscher & Grosch, (1997) [22] reported that 2-furfurylthiol, 4-hydroxy-2,5-dimethyl-3(2*H*)-furanone and 2-methyl-3-furanthiol were the most important odorants of boiled beef. 2-ethyl-3,5-dimethyl pyrazine and 2,3-diethyl-5-methylpyrazine possess roasty, caramel-like, burnt and earthy notes of roasted beef [23]. Other carbonyl compounds such as methional, E-2-undecenal, E-2-dodecenal, decanal, heptanal and 2-methylbutanal also were found to be associated with roasty, sweet, fruity and fatty odor notes of cooked beef [14,17]. Also, a great number of studies considered on the objective volatile flavor components in cooked pork, chicken, lamb, ham and etc… have been documented over the last years [24, 25, 26]. In fact, although thousands of volatile compounds identified but not all of them are important because their high odor detection threshold, only some of them play a significant role in the overall aroma flavor characteristics of cooked meat. An aroma flavor compound with its distinct odor note can be defined as its flavor dilution factor indicating that at the lowest concentration at which the compound still can be detected by the sense of smell. Some represent volatile flavors active-compounds have been detected in cooked meats by using gas chromatography-olfactometry technique (GC-O) are showed in Table 1.

Compound name	Aroma flavor characteristics
Aldehydes	
Methional	Cooked potato, meaty
E,2-nonenal	Fatty
E,E,2,4-decadienal	Fatty
Benzenacetaldehyde	Sweet, honey
E,E,2,4-nonedienal	Fatty
Decanal	Sweet, fruity, like aldehydes, roasty
Heptanal	Fruity, fatty, sweet, oil
Nonanal	Sweet, fatty, green
Undecanal	Sweet, pungent, green
E,2-heptenal	Fatty
E,2-heptenal	Fatty

Hexanal	Green, fatty
E,2-hexenal	Green
E,Z,2,6-nonadienal	Cucumber
Undecanal	Sweet, pungent, green
2-methylbutanal	Pungent, sweet, roasty
E,2-undecenal	Sweet, fruity, fatty
2,E-dodecenal	Sweet, fruity, roasty, pungent
Ethanol	Grilled (weak), acetaldehyde-like
3-methylbutanal	Meaty, fish, rotten, aldehyde,valeric acid, fatty
Octanal	Green, lemon, citrus, aldehyde
E,E,2,4-heptadienal	Aldehyde, green, broth, spicy
Propanal	caramel, sweet, alcoholic, "cooked", broth, spicy
Butanal	smoky, fish, amylic, aldehyde-enal or dienal
Ketones	
2-octanone	Fruity, musty
2-decanone	Fruity, musty
2-dodecanone	Fruity, musty
1-octen-3-one	fresh, mushrooms, pungent, rubbery
3-octanone	Fruity, nutty, moldy, fatty, earthy
2,5-dimethyl-4-hydroxy-3(2H)-furanone	Roasted almonds, sweet
4,5-dihydro-5-propyl-2(3H)-furanone	Fruity, fatty, sweet, pungent, roasty
2,3-butanedione	Sweet, buttery
2-heptanone	Citrus grapefruit, limonene, floral, cheese
2,3-pentanedione	buttery, lemon-like, sweet, fruity
2-nonanone	Hot milk, soap, green, fruity, floral
3-octen-2-one	Nut, crushed bug, earthy, spicy, sweet, mushroom,
6-Methyl 2-heptanone	Cloves, menthol
2-undecanone	Fruity
2,2,6-Trimethylcyclohexanone	Mint, acetone
Alcohols	
1-octen-3-ol	Mushroom
Cyclobutanol	Roasted

1-heptanol	Fragrant, woody, oily, green, fatty, winey, sap
1-hexanol	Woody, cut grass, chemical-winey, fatty, fruity
2-Ethyl 1-hexanol	Resin, flower, green
1-octanol	Penetrating aromatic odor, fatty, waxy, citrus, oily,
2-Octen-1-ol	Green citrus
1-pentanol	Mild odor, fuel oil, fruit, balsamic
Propanol	Alcoholic
Hydrocarbons	
Ethenylbenzene	Pungent, aromatic, fragrant, roasty
1-undecen	Fatty, burnt, nutty, rubbery
Hexane	Faint peculiar odor
(Z)-3-Octene	Fruity, old apples
Pentane	Very slight warmed-over flavor, oxidized
Styrene	Penetrating odor, sweet smell
Tridecane	Alkane
Tetradecane	Alkane
Ethenylbenzene	Aromatic, fragrant, roasty
Pyrazines	
2-ethyl-3,5-dimethylpyrazin	Burnt, fragrant, meaty, green
2-ethenyl-3,6(5)-dimethylpyrazine	Sweet, cooked rice, fatty
2-ethyl-3,6-dimethylpyrazine	Burnt, roasty
2,3-diethyl-5-methylpyrazine	meaty, roasty, fragrant, sweet
2,5-dimethylpyrazine	Fried rice, popcorn, pungent, green
2-ethenyl-5(6)-methylpyrazine	Roasty break-like, cooked rice, coffee-like
2,5-dimethylpyrazine	Fried rice, popcorn, pungent, green
2-ethyl-5-methylpyrazine	Fruity, sweet, pungent
2-ethenyl-5(6)-methylpyrazine	Smoky, roasty, break-like, cooked rice, popcorn
2-ethyl-3,6-dimethylpyrazine	Burnt, pungent, roasty
2-ethenyl-3,6(5)-dimethylpyrazine	Pungent, sweet, cooked rice, fatty
2,3-diethyl-5-methylpyrazine	Meaty, roasty, fragrant, sweet
2-isopentyl-3,6-dimethylpyrazine	Sweet, fragrant, fatty, fruity, pungent
Sulfur & nitrogen containing compounds	
2-fufurylthiol	Roasty

2-acetyl-1-pyrroline	Roasted, sweet
2-formyl-5-methylthiophene	Sulfurous
2-methyl-3-furanthiol	Meaty, sweet, sulfurous
Benzylthiol	Sulphurous
2,4-dimethylthiazole	Rubber y, moldy, fruity, pungent
2-acetylthiazole	Roasted
Dimethyltrisulfide	Fragrant, musty, roasty, rubbery
2-acethylthiophene	Sulphurous, sweet
Bis(2-methyl-3-furyl)disulfide	Meaty-like
Benzothiazole	Metallic
Dimethyldisulfide	Moldy, pungent, rubbery, onion-like
2,4-dimethylthiazole	Rubbery, moldy, fruity, pungent
4,5-dimethylthiazole	Smoky, roasty, fragrant, nutty
2-methylchinoxaline	Aromatic, roasted, nutty, sweet, fruity, fatty
3-mercapto-2-butanone	Fried onion, sulfury, cooked meat
2-mercapto-3-pentanone	Brothy, mashed potatoes meaty, roast meat
2-[(methyldithio)methyl]furan	Brothy, spices, roast, fatty
3-[(2-furanylmethyl)dithio]-2-butanone	onion, burnt rubber, burnt wood

Table 1. The representative volatile flavor compounds with their aroma flavor characteristics found in cooked meat. [References: 13, 14, 20, 15, 27]

2.2. Precursors of meat flavor

Earlier studies on meat flavor, researchers recognized that the low molecular weight, water-soluble compounds and fats in meat constituents are the most important precursor of aroma flavor characteristics of cooked meat [28, 29]. The flavor precursor of meat namely, free sugars, free amino acids, peptides, vitamin, sugar phosphate, nucleotide-bound sugars and nucleotides [30, 31, 32, 33], all of them are able to either participate the Maillard reaction or oxidation/degradation and interaction on heating to generate volatile flavor compounds then create the final aroma flavor characteristics of cooked meat. It is suggested that these precursor components found to contribute to the development of meaty flavor, while the adipose tissues and intramuscular fat not only occupy an important role in development of flavor characteristics of cooked meat but also contribute to the characteristic-specific species flavors. This means that the distinct flavor characteristics between the meats from different species are due to the intramuscular fat content and not from water-soluble precursor compounds. The details on flavor precursors of meat found in the past years are showed in Table 2. However, researchers found that the roles of these flavor precursors in the development of flavor characteristics

of cooked meat are not similar. Macey et al (1964) [28] found some sugars present in beef such as glucose, fructose, mannose and ribose, in that ribose was the most heat-labile sugar among these whereas fructose was the most stable. Among the amino acids present in meat, systein and systine are two sulfur-containing amino acids, the reaction of these with other sugars lead to formation of many sulfur-containing flavor compounds [34], while the reaction of other non-sulfur containing amino acids with sugars dominated by the nitrogen-containing products such as pyrazines [72]. In the recent years, researchers have found that the flavor precursor components in meats are influenced by several factors. Koutsidis et al (2008) [31] indicated that diets significantly affected the reducing sugars in beef *longissimus lumborum* muscle, higher total reducing sugars was obtained in beef from concentrate feeding group compared to the grass silage feeding group whereas beef from cattle fed with grass silage had higher level of free amino acids. When the beef was chiller aged for several days at chilling condition resulted in several times increase in free sugars such as ribose, free amino acids also increased with conditioning especially phenylalanine, methionine, lysine, leucine and isoleucine were the amino acids showing the greatest increase with conditioning time [32]. Meinert et al (2009) [35] have found that feeding, fasting and post-mortem ageing factors significantly influenced the concentration of flavor precursors of beef *longissimus dorsi* muscle. Additionally, the recent works also showed that fat-supplemented diets had large effect on the fatty acid compositions, for instance, dietary linseed oil and soybean oil significantly increased the contents of C18:3 and C18:2 in the neutral lipids and phospholipids in both *longissimus* and *biceps brachii* muscles [36], and subsequently influence the volatile flavor compounds of cooked beef [19, 25, 37].

Flavor precursors	Names in detail	Reference
Free amino acids	Systine; systeine; glycine; lysine; alanine; valine; isoleucine; leucine; threonine; serine; proline; asparagines; aspartic acid; methionine; glutamic acid; phenylalanine; glutamine; ornithine; histidine; tyrosine; tryptophan; arginine.	[38,39,40, 31,3232]
Reducing sugars	Ribose; glucose; xylose; starch; mannose; fructose; maltose; mannose 6-phosphate, glucose 6-phosphate; fructose 6-phosphate; ribose 6-phosphate.	[38,39,72, 41,31,32]
Fats/ lipids	Triglycerides and phospholipids Oleic acid (C18:1n-9) Linoleic acid (C18:2n-6) Linolenic acid (C18:3n-3) and etc.	[42,19, 43,34]
Vitamin	Thiamin	[33,44]
Nucleotides and peptides	Glutathione; carnosine inosine; inosine monophosphate; inosine 5'-monophosphate; guanosine 5-monophosphate; creatine; creatinine; Hypoxanthine and etc.	[45,44, 31,32]

Table 2. The representative precursors of meat flavor.

2.3. Pathways for the formation of volatile flavor compounds

2.3.1. Maillard reaction

Maillard reaction, a non-enzymatic browning which plays an important role in generation of volatile flavor compounds and appearances of the cooked foods, it is due to most of important volatile flavor compounds found in cooked foods are originated from this reaction. Otherwise, Maillard reaction also can produce antioxidative components and toxicological implications as well. However, in the present chapter we are focusing on the Maillard reaction in relation to aroma flavor characteristics, particularly the formation of volatile flavor compounds in cooked meat. Maillard reaction was firstly mentioned in the early time, 1912 by Maillard [46] since he wanted to investigate the browning reaction between glucose and glycine. After that many studies focused on determining the fundaments and mechanisms of this reaction [47, 48, 49].
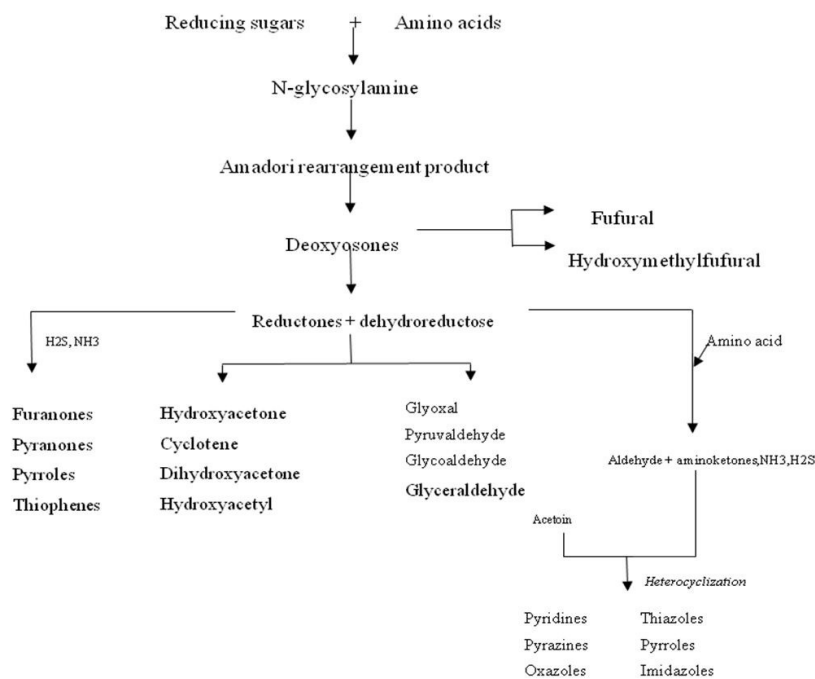

Figure 1. General stages of Maillard reaction showing the formations of flavor compounds (based on van Boekel, 2006) [51].

The Maillard reaction is taken placed with the participation of reducing sugars (e.g., ribose, glucose) and free amino compounds (e.g., amino acids, amines, peptides, proteins, ammonia) at certain heating condition to produce the Maillard products, and usually this reaction is divided into three main stages. In which the firstly initial stage starts with a condensation between a reducing sugar and an amino group, the loss of water from this molecule produces an amine that is able to cyclise resulting in formation of an N-glycosylamine (a sugar attached to NR_2 group) or called Amadori product. The next intermediate stage involves the rearrangement and decomposition of the Amadori product to release amino group and sugar fragmentation. The final stage of Maillard reaction is leading to dehydration, fragmenta-

tion, polymeration and cyclization reactions. A general scheme of the Maillard reaction is given in Figure 1.
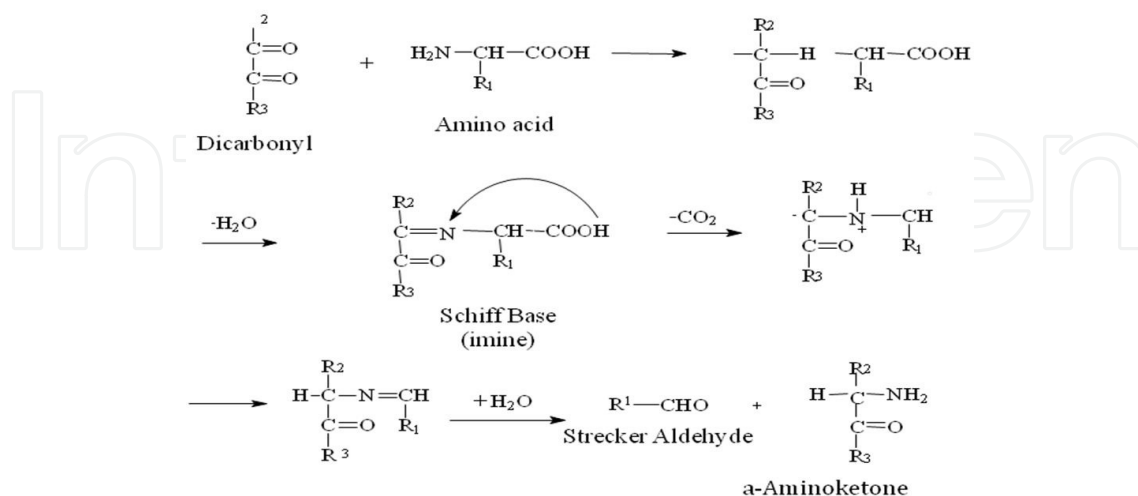

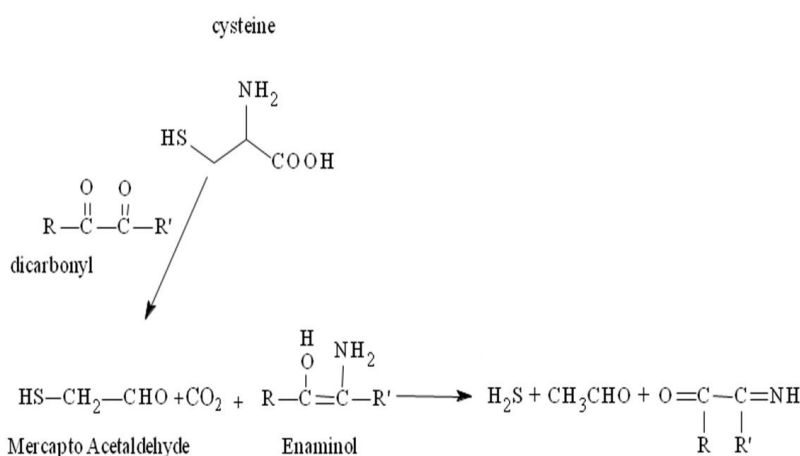**Figure 2.** Strecker degradation mechanisms, a part of Maillard reaction

Figure 3. The formation of H_2S from the Strecker degradation of cysteine

Among events occurring in the Maillard reaction, Strecker degradation is one of the quite important events, in which amino acids are undergone degradation processes (oxidative de-amination and decarboxylation) in the presence of a dicarbonyls compound formed from Maillard reaction. The Strecker degradation processes lead to formation of aldehydes (e.g., fufural) and aminoketone (Figure 2). Especially the other important intermediate products such as H_2S, NH_3, etc are also formed from the Strecker degradation by sulphur-containing amino acids such as cystein and systine (Figure 3); all of these intermediate products can further react with other compounds or with each other to produce low and high molecular weight end flavor compounds.
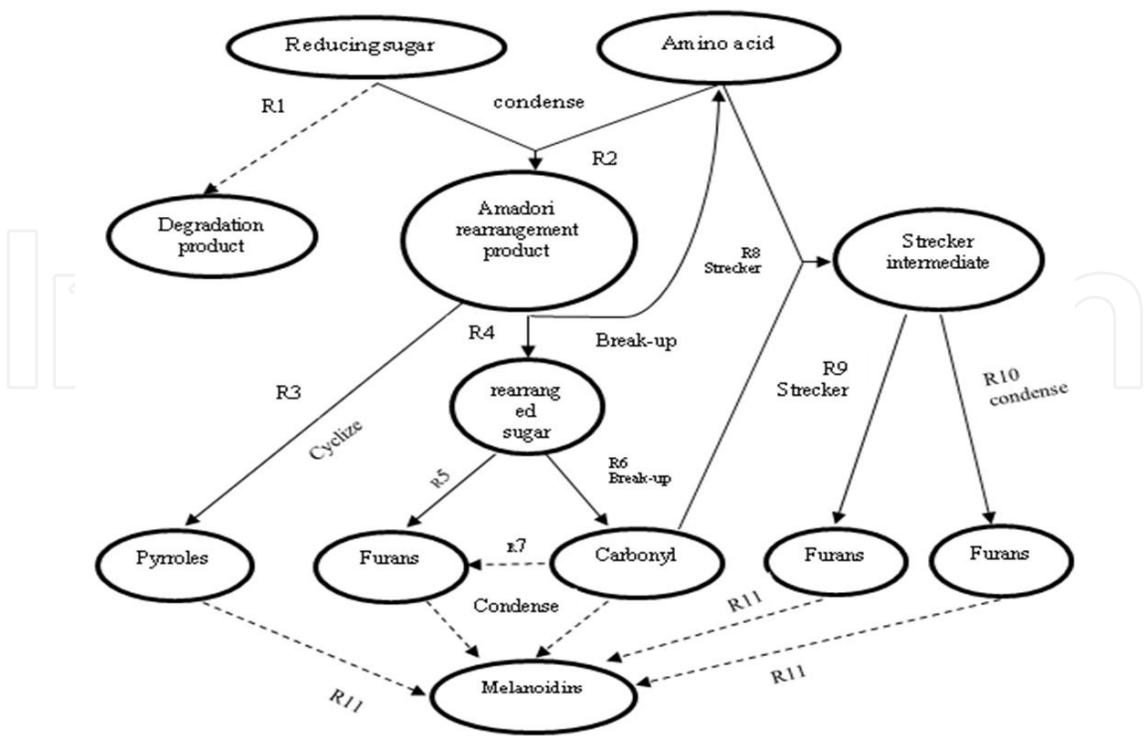
Figure 4. Kinetic scheme of flavor formation by Maillard reaction (Jousse et al., 2002) [50]

Flavor class	Characterized Flavor/aroma notes	Remark
Pyrazines	Cooked, roasted, toasted, baked cereals	
Alkylpyrazines	Nutty, roasted	
Alkylpyridines	Green, bitter, astringent, burnt	Unpleasant flavor
Acetylpyridines	Caracker-like	
Pyrroles	Cereal –like	
Furan, furanones, pyranone	Sweet, burnt, pungent, caramel-like	
Oxazoles	Green, nutty, sweet	
Thiophenes	Meaty	Formed from heated meat by the reaction of systein and ribose

Table 3. Some representative classes of flavor compounds formed from the Maillard reaction (based on van Boekel, 2006) [51].

The formation of volatile flavor compounds in the Maillard reaction largely depend on the reactants (e.g., the nature of reducing sugars and amino acids participated) and also the cat-

alytic condition (e.g., heating temperature, moisture, pH). For the type of reducing sugars and amino acids which determine the kinds of flavor compounds generated for instance, many sulfur-containing flavor compounds are formed from the Maillard reaction between systeine and ribose [34] whereas, the nitrogen-containing compounds (e.g., pyrazines) dominated in the Maillard reaction containing glucose and lysine [72]. Therefore, it should be noted that nature of reactants will require the kinds of Maillard products. For the catalytic condition of Maillard reaction, it usually influences the kinetics of flavor compound generation by Maillard reaction in that depending on each catalytic condition (temperature, pH and etc) will determine the yields and also kinds of Maillard products. The kinetic of flavor compound formation resembles the scheme in Figure 4 with 11 determining steps [50]. Based on the kinetic scheme it shows that there are many chemical classes of flavors are formed via the Maillard reaction, some of the representative classes associated with odor notes are showed in Table 3.

2.3.2 Lipid oxidation and degradation

Lipids and fatty acids play an important role in direct and indirect generating the volatile flavor compounds and some of them contributing to the aroma flavor characteristics of cooked meat. Therefore, the levels of fat contents and as well as fatty acids of meats should be concerned, and it has been reported that the fatty acids of meat are influenced by several factors but almost are the pre-harvest factors such as diets, feed regimes and breeds [52, 53, 54]. Based on our surveillance it seems that the fatty acid profiles significantly vary across the breeds even these breeds are fed with the same diets [55, 56, 57]. Both adipose tissue and intramuscular fat contents are constituted by fatty acids including saturated and unsaturated fatty acids which all are capable to get oxidized and degraded under a certain condition to create a prolific number of volatile flavor compounds [2]. Hundreds of volatile flavor compounds derived from lipid degradation have been found in cooked meat including aliphatic hydrocarbons, aldehydes, ketones, alcohols, carboxylic acids and esters. In general, the odor detection threshold values for the lipid-derived compounds are much higher than those for the sulfur and nitrogen-containing heterocyclic compounds which are formed from the water-soluble precursors via the Maillard reaction. Therefore, the aroma significance of many of these lipid-derived compounds is not as great as that for relatively low concentrations of the heterocyclic compounds. However, certain classes of compounds such as particular aldehydes included saturated and unsaturated aldehydes which containing from 6 to 10 carbons in the structures are major volatile components of all cooked meats and, therefore, they probably play an important part in meat aroma [20]. The oxidation of subcutaneous fat, adipose tissues and intramuscular fat occur in raw meat and continues under the catalysis of many factors such as metals, oxygen, light, heating and etc.

Among the oxidation-induced factors for instance, lights (e.g., ultraviolet) is thought to be thermodynamically capable of production of free radicals directly in lipids, the principles of light-absorbing groups of lipids are double bonds, peroxide bonds and carbonyls which subsequently under the other steps to generate volatiles. And other factors such as oxygen, lypoxygenase, metals and etc which all also affect the lipid oxidation however that is anoth-

er concern, in the present work we only consider on the heat effect that similar to cooking condition to induce the oxidation and degradation of fatty acids in producing volatile flavor compounds of cooked meat. The degrees of heating temperatures have been reported to affect variously lipid oxidation, in that high heating temperatures (e.g., frying, roasting) can have highly sufficient energies to break the single bonds (e.g., C-C or C-H) in the acyl back bonds to generate a lot of lipid alkyl radicals that participate the radical chain formation of oxidation [58]. Lower heating temperatures have lower energies which can break O-O bonds in traces of ROOH. Mottram (1985) [59] also stated that meat is cooked under boiled and lightly roasted conditions, lipid oxidation products dominated the detected compounds, and many of among them such as aldehydes, alcohols, ketones and lactones which have sufficiently low odor threshold to be contributors of meat aroma flavors.

Early work of Mottram et al (1982) [60] found that lipid has a considerable role in meat flavor, when the adipose tissue is added to lean meat does not affect the lipid-derived flavor compounds. A later study by Mottram and Edwards (1983) [42] found that the removal of intramuscular fats and phospholipids from beef caused marked differences in flavor compounds and sensory characteristics as well. So that the intramuscular fat contents (marbling fats) and membrane lipids are the main source of volatile flavor components and make species-specific flavors. However, it has been demonstrated that high levels of lipids especially polyunsaturated fatty acid contents (PUFA) cause undesirable aroma flavors due to their PUFA-derived products lower or inhibit the formation of some heterocyclic Maillard products [42]. This phenomenon has recently been elucidated by researchers when they used model systems. In the model systems containing systeine, ribose and lipid (e.g., lecithin or individual fatty acids) the concentrations of heterocyclic compounds and especially sulfur-containing compounds were lower several times compared with the model system without lipid content [43, 38, 61, 34]. However, the interaction between the lipid-derived products with Maillard products to form volatile flavor components has been much considered in the previous studies and thought as the important pathway for formation of flavor compounds.

2.3.3. Thiamin degradation

Thiamin is considered as a source of meat flavor generated on heating. Researchers found that the thermal degradation of thiamin produces some ended and intermediate flavor compounds [62,63]. It was assumed that thermal degradation of thiamin is a quite complex reaction including various degradation pathways to produce interesting flavor compounds in which most of them contain one or more sulfur and/or nitrogen atoms, and many of them are heterocyclic structures. The thermal degradation of thiamin under the basic condition to produce several flavor compounds is illustrated in Figure 5.

It was reported that the primary products of thermally-degraded thiamin including 4-methyl-5-(2-hydroxyethyl)thiazole which subsequently responds for formation of thiazoles and other sulfur compounds such as 5-hydroxy-3-mercaptopentan-2-one which then gives some sulfur-containing compounds such as thiophenes and furans as well [62]. Heating temperature and pH conditions have been showed to affect the degradation products of thiamin. At pH 5.0 and 7.0 the 2-methyl-3furanthiol and bis (2-methyl3-furyl) disulfide (meaty aroma)

and thiophenes were the dominant aroma volatile compounds. But the levels of these meaty compounds decrease when increasing pH to 9.0 [64]. Similarly, a recent study by Dreher et al (2003) [65] also showed that the most significant thiamin thermal degradation products in the model reaction of orange juice containing 0.024 mM thiamin are 2-methyl-3-furanthiol and bis(2-methyl-3-furyl) disulfide produce intense meaty aromas. Otherwise, some other aroma-active compounds also were found such as 4, 5-dimethylthiazole (skunky, earthy), 3-thiophenethiol (meaty, cooked), 2-methyl-4, 5-dihydro-3(2H)-thiophenone (sour-fruity, musty, green), 2-acethylthiophene (burnt), 2-formyl-5-methylthiophene (meaty), and 2-methyl-3-(methyldithio) furan (meaty).
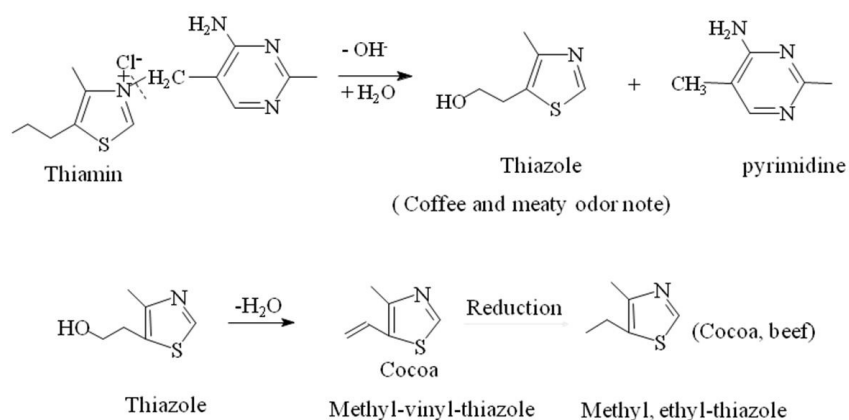

Figure 5. The thermal degradation of thiamin under basic condition

2.3.4. Interaction between lipid-oxidized products with Maillard products

The interaction between oxidized lipids and amino acids or proteins is very complex, in term of a consequence of the contribution of both lipid hydroperoxide and its secondary-oxidized products. This interaction may imply both the formation of physical complexes between the oxidized lipids and the amino acids or protein and the formation of various types of covalent bonds. Protein polymerizarion produced by reaction with peroxy free radicals generated during lipid peroxidation is known to occur during nonenzymatic browning [66, 67, 68]. However, in term of flavor study, the interaction between lipid-oxidized products (secondary products) with amino acids or proteins is the most concerned. Lipid-oxidized products are generic terms used to describe a mixture of aldehydes, alcohols, ketones and other products obtained by the decomposition of lipid hydroperoxides. Although it is not widely recognized, this decomposition does not necessarily imply the breakage of the lipid chain, and the formation of covalent bonds in the reaction between long chain oxidized lipids and amino acids and proteins has been described [69, 70]. This is a consequence of the existence of fatty acids that produce a complex and diverse mixture of lipid oxidation products that are able to react with the different reactive protein residues.

In the Maillard reaction, amino acids can undergo the Strecker degradation process that subsequently generates some reactive radicals such as ammonia, hydrosulfide and etc which al-

so are able to further react with the secondary oxidized products of lipid to produce volatile flavor compounds such as thiols, thiophenes, thiazoles and etc as showed in Figure 6.

The interaction between lipid and Maillard reaction have extensively been studied in a number of studies using model systems containing amino acids and sugars in the presence of lipid [43, 61, 39, 34]. In these studies, systeine and ribose were used for Maillard reaction and in the presence of phospholipids from various sources including egg-yolk and beef. The reaction mixtures produced a lot of aroma volatiles which dominated by sulfur-containing components especially heterocyclics such as thiols and thiophenes. These studies also observed that the presence of phospholipids made a great reduction in amounts of these compounds. Famer and Mottram (1990) [61] also noted that beef-originated triglyceride has much less influence on amounts of heterocyclics than the phospholipids from beef do. The study also found that the addition of beef triglyceride to the Maillard reaction did not influence the sulfurous and rubbery aroma but when beef phospholipids were added resulting in higher meaty aroma note whereas the sulfurous notes were less. However, the Maillard reaction systems containing phospholipids usually had lower level of some meaty compounds especially 2-methyl-3-furanthiol this is due to the lipid limits generation of these compounds and only maintain theme at an optimum level in the reaction mixture.
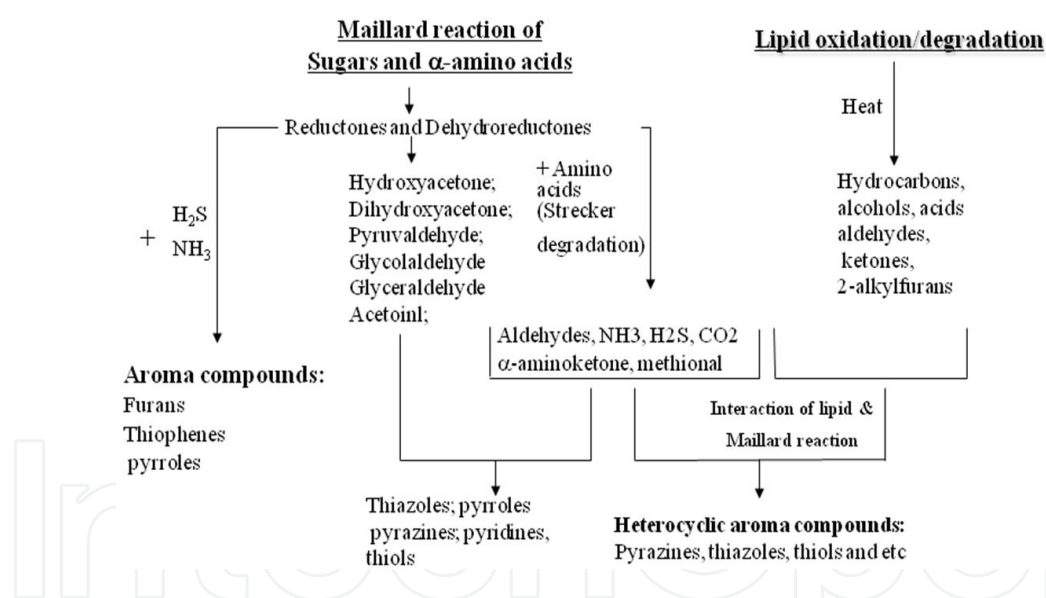

Figure 6. The interaction between lipid-oxidized products with Maillard products.

In general, in Maillard reaction mixtures containing lipids produce a lot of lipids-derived volatile compounds such as aldehydes, furans, hydrocarbons, alcohols and ketones. Furthermore, the reaction mixtures also containing the Maillard products such as H_2S, NH_3, etc. Which all are able to interact with each other to form new heterocyclic aroma volatile compounds as the consequences of the interactions between lipids with Maillard products. The most abundant compounds have been detected as results of the interactions are thiophene class such as 2-pentylthiophene, 2-hexylthiophene and thiol class such as 2-thiophenethiol, 2-furylmethanethiol, 2-methyl-3-furanthiol and etc [38, 61]. A recent study by Elmore and

colleagues (2002) [34] concluded that breakdown products of polyunsaturated fatty acids especially are n-3 acids have a shorter chain length have lower odor thresholds will also be present at relatively high concentrations and are more reactive. These breakdown products will affect meat flavor by interacting with the Maillard reaction reducing levels of meaty aroma compounds, such as sulfur-substituted thiophenes and furans. As n-3 PUFAs are readily oxidized, they could initiate the free radical oxidation of more saturated acids, increasing levels of breakdown products of n-6 and n-9 fatty acids, which may also alter the aroma compounds of the cooked meat.

3. The factors affect aroma flavors

3.1 Effect of diets

Diet is as an important indicator to show the growth rate, performance, reproducibility effects and as well as meat quality of cattle. There has been an existed hypothesis of meat flavor changes due to feeding diets in which some works stated a large difference in meat flavor characteristics of the same cattle breed but fed on different diets. Early work by Melton (1983) [71] stated that steers fed with corn-based diets had more intense beef flavor (desirable flavor) than the same age steers fed based pasture or Bermuda pellets. A later study of Melton (1990) [10] found that the less desirable flavor of meat from cattle is mainly caused by several grass species. Conversely, no significant difference in flavors existed between the grass and grain diets-fed animals [73]. The less desirable flavors were also seen on meats from the hay diets-fed animals compared to corn silage diets [74], while Oltjen et al (1971) [75] showed the opposite results. It has been hypothesized that majority of flavor effects due to feeding of forages is mainly due to changes in fatty acid compositions. Fishy off-flavor was significantly higher in meat from grass-finished cattle with increasing unsaturated fatty acids [76]. Recently, researchers have attempted to higher level of PUFA in meat aiming to increase the health benefits by using the fat supplemented-diets (e.g., linseed, sunflower oil and fish oil) to cattle [77, 78], although these works have achieved an increase in several benefit fatty acids however, the detrimental effects on meat flavor characteristics appeared due to higher levels of PUFA [79]. A large number of studies regarding the effect of diets on volatile flavor compounds of cooked meat have been performed. Melton (1983) [71] also noted that the greatest difference in the flavors of meat from cattle fed on grass and grain-based diets is due to fatty acid concentration and type as fatty acids are the primary source of carbonyl. Suzuki and Bailey (1985) [80] indicated that higher concentrations of pentanoic,heptanoic, octanoic, nonanoic, decanoic, and dodecanoic acids were formed in the meat fat from grass-fed animals while heptanal, 2,3-octanedione, 3-hydroxyoctan-2-one, 2-decenal, 2-tridecanone, hexadecane, heptadecane, octodecane, d-dodecalactone, phyt-1-ene, neophytadiene, phyt-2-ene, an isomer of neophytadiene, 2-heptadecanone, dihydrophytol, and phytol with the terpenoids in much higher concentration due to rumen-fermented chlorophyll. Individual volatile flavor compounds like 4-heptanal, 2, 4-heptadienal and 2, 6-nonadienal (derived

from C18:3n-3) and hexanal, 2-heptanal and 2, 4-decadienal (derived from C18:2n-6) found to be higher concentration in meats from grass and grain-fed animals, respectively [81]. El-more et al (1997) [82] also reported that cooked meat from the animals that had been fed fish oil had considerably higher concentrations of saturated and unsaturated aldehydes than meat from the control. While, Descalzo et al (2005) [83] found that some classes of volatile flavor components affected by diets in which aldehydes increased in meat from concentrate diets-fed animals. In general, we can see that diets have a large influence on meat flavors due to directly affect the meat contents especially the intramuscular fat contents which play an important role in interaction and generation of volatile flavor compounds. On the other hand, it is worth noting that the uses of fat –supplemented diets to feed cattle may result in increases of important polyunsaturated fatty acids (e.g., n-3 fatty acids, DHA, EPA) which known to positively affect on consumers health however, a negative effect on meat flavors may appear due to these fatty acids not only produce some unexpected volatile compounds but also inhibit production of other Maillard products.

3.2. Effect of breeds and sex

Researchers have reported that breed also affects volatile flavor components and then influ-ence overall flavor notes of cooked meat. Elmore et al (2000) [25] stated that fifty-four com-pounds were affected by breed, 75% of which was Maillard reaction products. Over 40 compounds were present at higher levels in the Soay breed than in the Suffolk breed. Other sulfur-containing compounds present at higher levels in the Suffolks than the Soays were bis-(2-furylmethyl) disulfide and 2-methyl-4,5-dihydro-thiophene and the differences in sul-fur and nitrogen-containing compounds could contribute to flavor differences between the two breeds. A study on pork flavors as affected by breeds also have found that twenty-three among the detected flavor compounds were significantly affected by breed. Based on senso-ry analysis indicated that cooked *longissimus* muscle from hybrid breed (Duroc x Landrace x Large White) had the lowest pork flavor intensity and flavor-liking compared with the Chi-nese indigenous breeds. Laiwu and Dahuabai breeds showed the highest pork flavor inten-sity and flavor-liking in cooked longissimus muscle [36]. In beef, Insausti and colleagues (2005) [84] also found the differences in volatile flavor compounds among the breeds were considerable and may contributed to the perception of flavor differences in the cooked beef. Particularly, level of dimethyl sulfide probably related to cauliflower notes, was highest for meat from the Pirenaica breed. While, levels of the sulfur-compounds in cooked beef from the Asturiana breed were low-intermediate and potentially related to blood and liver notes and unpleasant flavors.

For the sex effect, it has been reported that meat from bulls has a strong livery and blood flavors while meat from heifers has a strong characteristic flavor. The differences could be associated with the differences in amounts of certain volatile compounds such as hydrocar-bons, aldehydes, alcohols and ketones [85]. On the other hand, the differences in meat fla-vors between bulls and heifers could be explained by the genetic control of animal development and production of sex hormones and their influence the lipid composition which affects the kinds of volatile flavor compounds [86]. Overall, it may be assumed that

the differences in meat flavors existing between breeds or sexes are probably due to the differences in the levels of flavor precursors especially the fat contents which large affect the formation of aroma flavor compounds and also interact with other contents in determining flavor characteristics of cooked meat.

3.3. Effect of chiller ageing

Ageing has been become a universal method widely used to improve eating quality of meat (e.g. tenderness, juiciness, flavor). Un-aged beef has a weak, bland odor while aged beef has a strong, savory, roasted odor. Ageing of meat makes an increase in fatty flavor characteristics however; long term ageing (e.g., > 3 weeks) could cause a decrease in positive flavor notes and increase liver-like aroma, bloody, bitter and off-flavor [87, 85, 88]. Ismail et al (2008) [89] stated that ethanol was responsible for the increase in alcohols caused by the microbial growth in beef during storage furthermore, the levels of aldehydes significantly increased after 7 days of storage. Beef from various muscles including gluteus medius, rectus femoris, vastus lateralis, vatsus medialis, teres major, complexus, serratus ventralis, psoas major and longissimus dorsi of heifer carcasses were chiller aged for 7 or 14 days the results showed that flavor-active volatiles included nonanal, 2,3-octanedione, pentanal, 3-hydroxy-2-butanone, 2-pentyl furan, 1-octen-3-ol, butanoic acid, pentanal and hexanoic acid which all often associated with lipid oxidation were affected by enhancement and ageing in the various muscles [90]. Additionally, ageing of beef achieved an increase in characteristic flavor and also aftertaste intensity, making an appreciable improvement of its flavor. After slaughter, loss of circulatory competency results in the accumulation of metabolic by-products, including lactic acid, in the muscle, that induces pH decline. The endogenous enzymes (e.g., cathespins B and L) are activated at near pH 5.4. Spanier and Miller (1993) and Spanier et al (1990) [91, 92] suggested that these thiol proteinases can hydrolyze more peptide bonds than any other group of enzymes, are redistributed during ageing period. Proteolytic enzyme activity is temperature-dependent; some enzymes retain high activity levels even at cooking temperatures. The combined effect of postmortem ageing and cooking, via enzyme redistribution and activity can influence the production of aroma flavor compounds. Toldrá and Flores (2000) [93] stated that enzymes known primarily for textural changes (e.g., μ- and m-calpain) during the postmortem period affect flavors by producing peptides, but it was observed that these enzymes correlate with increases in rancid, sour and salty flavors. The ageing conditions (e.g., oxygen availability, temperature, humidity and aging time) under which beef is aged influences the ultimate flavors of the meat particularly ageing in a higher oxygen environment cause a burnt, toasted off-odor. In addition, dry-ageing increases beef flavor attributes more than ageing in vacuum or in carbon dioxide [94, 95]. Based on the results reported in the previous studies it could be concluded that chiller ageing of meat resulted in increases of most of flavor compounds however a long ageing period (e.g., > 3 weeks) may negatively influences the flavor quality of cooked meat due to increase in amounts of some unexpected compounds which associated with undesirable flavors and decrease in the some important compounds which associated with desirable flavors.

3.4. Effect of cooking temperature and pH conditions

Cooking temperature is one of the important factors impacting the development of flavors through the Maillard reactions and lipid oxidation. Amino acids can undergo Strecker degradation to produce Strecker products. Degradation of sulfur-containing amino acids (e.g., cysteine, cystine and methionine) generates sulfur that contributes to subsequent processes of Maillard reaction. These compounds can react with amines and amino acids to produce a number of flavor-contributing compounds and potent cooked meat odorants such as pyrazines, oxazoles, thiophenes, thiazoles and other heterocyclic sulfur containing compounds [20]. It was well seen that cooking temperatures affect these reactions and then determine flavor characteristics, for instance the stewed meat lacks flavors of the roasted products because of stewed meat has a water activity of approximately 1.0 and not exceed temperature of 100°C while roasted meat has dried surfaces and temperature may exceed 100°C therefore, the conditions like low water activity and high surface temperature will increase production of flavor compounds which give roasted odor notes rather than meat is stewed. Ames et al (2001) [40] concluded that the amounts of most volatile flavor compounds increased with cooking temperature. Cooking at lower temperatures (<165 °C) versus higher temperatures (>180 °C) results in differences in the concentrations of a number of compounds such as 2, 4, 5-trimethyl- 3-oxazoline; 2, 4-dimethyl-5-ethyl-3-oxazoline; 2, 5- dimethyl-4-ethyl-3-oxazoline; 2, 4-dimethyl-3-thiazoline; 2, 4, 5-trimethyl-3-thiazoline [96]. Previous works found that a strong relationship existing between cooking temperature, concentration of free amino acids, carnosine, pyrazines and hexanol, and roasted, burnt and beefy flavor intensity [97, 98]. Cooking beef generates urea content which can also reduce sulfur-containing compounds generating important nitrogen-containing compounds like pyrazines and thiazoles in which pyrazines are formed mostly on the surface of meat and having nutty and roasty odor notes [99]. In general, the higher degree of heating, the higher the concentration of aliphatic aldehydes, benzenoids, polysulfides, heterocyclic compounds and lipid-derived volatiles. Ketones, alcohols sulfur-containing components make smaller contributions.

pH is one of the important factors that influence the kind of volatile flavor compounds formed in the Maillard reaction, and then determine the final flavor characteristics of cooked food. Madruga and Mottram (1995) [8] showed that as pH increases, color and polymeric compounds increase and nitrogen-containing compounds like pyrazines are favored, therefore it was assumed that higher ultimate pH in meat from grass-fed animals may favor the formation of thiazoles and thiophenones due to the availability of amino acid degradation products while decreasing other sulfur volatiles that favor lower pH. A number of early studies have been performed to investigate the effect of pH changes on volatile flavor compounds using model systems (El'Gde et al., 1966; Shu et al., 1985; Meynier and Mottram, 1995) [100, 101, 102]. These studies found that high pH values also favor the formation of many volatile compounds but other compounds are only favored at low pH condition. Meynier and Mottram (1995) [102] used meat-like model systems containing amino acids and ribose on different pH 4.5 and 6.5, results showed that nitrogen-containing compounds such as pyrazines were detected at higher pHs. While, dimethyldisulphide and methional

showed decrease as the pH increased, and an increase in the disulphide was observed. It was observed that a large number of sulphur-containing compounds such as 2-methyl-3-fur-anthiol a strong meaty aroma, whose formation was greatly favored by lower pH condition. Ames et al (2001) [40] used model reactions containing cysteine and reducing sugar at varied pH conditions 5.5, 6.5 and 7.5, results showed that amounts of most of compounds increased with pH especially are pyrazines. Cerny and Biffod (2007) [103] recently found that pH determined strongly which volatile flavors were formed and to what extent. In general, based on the results of the previous studies which all found that pH condition strongly influence the formation of flavor components.

3.5. Effect of irradiation on meat flavors

Irradiation is a food safety technology designed to eliminate disease-causing germs from foods. Depending on the dose levels of irradiation applying on the raw meat and poultry, or ready-to-eat meats that can eliminate bacteria commonly found such as E. coli, Salmonella and Listeria; virus; or parasites. However, irradiation may result in off-odors and flavors. The odors vary with the type of meat, temperature during irradiation, oxygen exposure during and/or after the irradiation process, packaging and presence of antioxidative substances [104]. Most of studies have reported that the aroma flavors of irradiated meat associated with rotten egg, sweet, bloody, cooked meat, barbecued corn, burnt, sulfur, metallic, alcohol, acetic acid, liver-like serumy and bloody [105, 106, 107]. Irradiation can initiate or promote lipid oxidation resulting in undesirable off-odors and flavors [108, 109]. Jo and Ahn, (2000) [110] showed that reactions of sulfur-containing amino acids with radiolytic products of water appear to be the source of hydrogen sulfide and other volatile sulfur-containing compounds which contribute to off-flavor. On the other hand, irradiation may result in the formation of free radicals from unsaturated fatty acids at double bond positions [109]. An increase in lipid peroxidation products such as hexanal and (E)-4,5-epoxy-(E)-2-decenal in combination with a loss of desirable meaty odorants (4-hydroxy-2,5-dimethyl-3(2H)-fura-none and 3-hydroxy-4,5-dimethyl-2(5H)-furanone) result in development of warmed over flavor of cooked, refrigerated beef [16]. However, the effects of irradiation on aroma flavors are also depended on: (1) Dose levels of irradiation, it has been demonstrated that the dose levels of irradiation influence variedly on volatile flavor components of cooked meat, as reported by Jo and Ahn (2000) [110] who indicated some of hydrocarbons included 1-heptene and 1-nonene increased with irradiation dose immediately after irradiation of beef. A similar observation also was reported by Yong et al (2000) [111] who indicated that among the 150 flavor compounds indentified in beef the cyclodecene, (E)-2-hexenal, nonene and 2-nonenal showed an increase in a dose-dependent fashion. For the effect of irradiation on chicken flavors, Yong e al (2000) [112] showed that among the 129 identified volatile flavor compounds the cyclotetradecene, 2-methylpentanal and 4-methylcyclohexene were formed specifically in response to irradiation, and level of cyclotetradecene increased in a dose-dependent fashion; (2) Oxygen presence, the presence of oxygen around meats during irradiating can diffuse into the meats, and then results in radiolytic changes which precipitate oxidation and unacceptable secondary breakdown products. As well known, lipid oxidation needs oxygen presence to produce oxidized-products such as aldehydes, Nam and Ahn

(2003) [113] indicated that irradiation of meat in aerobic packaging promoted production of aldehydes such as propanal and hexanal which is assumed as a good indicator of lipid oxidation. The similar observation also was reported by Nam et al (2001) [114] who also showed that irradiation increased TBARS values and off-flavor in aerobically-packaged pork (3) Temperature effect, temperature during irradiating meats has a large effect on aroma flavors of irradiated meat because temperature affects what radiolytic products are formed and what ratios [104]. Using lower temperature during irradiation of meat by freezing meat before irradiation can reduce detrimental effects via retarding autoxidation and extending shelf life; (4) pH effect, it has also been demonstrated that the ultimate pH of meat at the time of irradiation influences lipid oxidation. Nam et al (2001) [114] recently showed that irradiation increased lipid oxidation of normal and pale-soft-exudative (low pH group) muscles, whereas dark-firm-dry (high pH group) muscle was very stable and resistant to oxidative changes. Therefore, to minimize the detrimental effects of irradiation on aroma flavor characteristics we can modify atmosphere packaging by using vacuum packaging (anaerobic packaging) or replacement with inert gases (i.e. nitrogen, helium, hydrogen, carbon dioxide) to eliminate oxygen. Reducing the temperature (freezing) prior to irradiation and addition of antioxidants. Vacuum packaging retains irradiation-generated sulfur-containing compounds, however re-packaging meat in oxygen-permeable materials allows for dissipation of these flavor compounds.

4. Warm-off flavor and liver-like off flavor in cooked meat

Warm-off flavor and liver-like off flavor are undesirable flavors that result from the flavor changes and deterioration in meats that have been pre-cooked, chilled-stored and reheated. The warm-off flavor includes odors and tastes commonly described as stale, cardboard-like, painty, rancid, bitter and sour [115], and together with liver-like off flavor they both are the main factors that negatively affect eating sensory quality, purchase, economic impact of meat industry, and consumer complaint. Researchers have found that warm-off flavor appearing in cooked meat is mainly caused by oxidation of membrane phospholipids [116,115]. A recent report of Byrne et al (2001) [117], which also demonstrated that warm-off flavor associated with the development of lipid oxidation derived nuance off-flavor and odor notes such as rancid-like flavor and linseed oil-like odor, in association with a concurrent decrease in cooked pork meat-like flavor. The development of warm-off flavor usually results in loss of meaty flavor due to mask by lipid-oxidized products. Additionally, processes which involve any action that disrupts the muscle fiber membrane, such as chopping, restructuring, or heating which all can enhance warm-off flavor of meat product [118]. Previous works also suggested that reactions involving sulphydryl–disulfide interchanges in proteins and the degradation of sulfur-containing heteroatomic compounds, leading to a decrease in the ''meatiness'' of freshly cooked meat may also be an integral part of warm-off flavor [119,120]. For the liver-like off flavor of cooked meat, it was hypothesized that since foodservice preparation traditionally cooked the meat quickly and then held the product in warming ovens until the food was presented to the consum-

er these conditions might promote the liver-like flavor [27]. James and Calkins, (2005) [121] also hypothesized that the slower cooking and longer hold time allow the undesirable volatile flavor compounds to dissipate.

5. The current techniques used for extraction and detection of aroma flavor components

Up to present time, various techniques have been designed, combined with gas chromatography and mass spectrometry (GC/MS) or Flame ionizing detector (GC/FID) and applied to evaluate volatile flavor components in cooked meat. Of which, simultaneous steam distillation-extraction (SDE), dynamic headspace entrainment on Tenax TA, and solid-phase micro-extraction (SPME) are the techniques widely used for the extraction of volatile compounds in cooked meat [19, 122, 123, 85, 90, 124, 18,125]. SDE is a simple technique which involves small volumes of solvent, efficient stripping of volatiles and quantitative recovery of many compounds. The sample is dispersed in water which is heated to boiling. The steam that is generated carries volatiles with it into a section of the apparatus where the steam condenses in the presence of extracting solvent vapor. The co-condensation of volatile-laden steam and extracting solvent results in an effective extraction of volatiles [123]. The Dynamic headspace entrainment on Tenax has been used in the studies regarding cooked meat volatile flavor compounds since the 1980s. This technique probably has been used more than any other aroma extraction technique for the analysis of meat aroma and continues to be widely used. The action mechanism of this technique involving purging the headspace of a sample with a purified inert gas (e.g., nitrogen or helium), followed by collection of the volatiles onto a trap containing a suitable adsorbent, which will retain the volatile analytes carried there by the purge gas. Finally, the volatiles of meat samples collected on this trap are desorbed onto a GC or GC-MS column using a modified injection port. In the recent years, SPME technique has been widely adopted and considered as an alternative to isolate volatile flavor components in cooked meat. In SPME, the needle is coated with an absorbent material (e.g. CAR/PDMS), is placed above the cooked meat samples. Volatiles will migrate from the sample matrix to the needle coating and be absorbed. Volatile components will then be desorbed from the needle coating by inserting the needle in GC injection port.

The extraction techniques as mentioned above in combination with GC/MS or GSC/FID can help researchers to tentatively detect the volatile flavor compounds in experimented meat samples but it could not identify the aroma flavors or odor characteristics of detected compounds. It would be advantageous to combine two or more different techniques, such as gas chromatography (GC) and olfactometry, the combination of measuring odor notes is called gas chromatography-olfactometry (GC/O). Gas chromatography-olfactometry (GC-O) is a bioassay that measures human response to odorants separated by gas chromatography. The superior sensitivity and selectivity of human olfaction make GC-O a powerful and meaningful tool for flavor chemistry. In the recent year, GC-O is one of the main techniques which have been used to determine intensity of aroma (odor) characteristics of volatile compounds in cooked meat [15, 21, 125].

6. Conclusion and Implication

In order to have a cooked meat product with its desirable aroma flavors as expectation of consumer, it is important to understand how aroma flavors are derived, the mechanisms by which flavor components are generated, and the factors affect formation of flavor compounds then determine the final aroma flavor characteristics of cooked meat. Regarding the effects of factors on aroma flavors of cooked meat and to minimize the detrimental effects it is suggested if increasing the polyunsaturated fatty acids (e.g. C18:3n-3, DHA, EPA) to increase nutritional benefits to the consumer by using fat-supplemented diets however the undesirable flavors may result. Because the breakdown products of these fatty acids have a shorter chain length therefore are more volatile and they affect meat flavors by interacting with the Maillard reaction results in reducing levels of meaty aroma compounds such as sulfur-substituted thiophenes. Therefore, diets, feeding regimes, welfare and management of animals should be taken into account. Cooking conditions such as temperature, holding time and cooking methods play an important role in determining the formation volatile flavor compounds. In general, it has been demonstrated that cooking meat at high temperature (by roasting, grilling) will produce better aroma flavor characteristics due to the important Maillard products are formed. In addition to the cooking effect, it is suggested that a slow cooking and longer hold time can allow the undesirable volatile flavor compounds to dissipate, thus reduce warm-off flavor. Irradiation of meat can eliminate pathogens however, off-flavor may result therefore, and to minimize the detrimental effect of this method we can lower temperature during irradiation of meat by freezing meat before irradiation. Modifying atmosphere packaging by using vacuum packaging (anaerobic packaging) or replacement with inert gases (i.e. nitrogen, helium, hydrogen, carbon dioxide) to eliminate oxygen in meat during irradiation are also the alternatives. Chiller ageing of meat should be applied to improve eating quality however should not age for a long time (3 week period in maximum is encouraged) because chiller ageing meat for a too long period may result in flavor deterioration and decreasing desirable flavors.

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