Flavor Development and Relating Volatile compounds to Sensory Evaluation

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INTRODUCTION

Flavor is an important component of meat taste to consumers. In the late 1800s, documented efforts first appeared to formally improve meat flavor in a controlled manner (Chemiox, 1874). For more than 140 years Americans have sought to document and improve flavor with patented discoveries and research (Chemiox, 1874; Filbert, 1909; and Howe and Barbella, 1937). In fact, Howe and Barbella (1937) noted that very little evidence existed as to the chemical characteristics of meat flavor. They surmised it was likely a composite of salts, acids, and a group of products resulting from heating, and it most likely involved the disintegration products of proteins and lipids.

Shepherd (2005) reviewed the theory of olfactory processing and its importance to flavor and aromas. Of particular note is the fact that cells in the olfactory bulb are sensitive to one-carbon differences between stimulating molecules, demonstrating the degree of sensitivity of human smell. Shepard (2005) concluded that odor ‘images’, combined with taste, somatosensation, vision and hearing, together with motor manipulation, provide the basis for the perception of flavor, which is a higher cognitive function uniquely developed in humans with the help of language.

Wasserman (1972) described raw meat, and “in general has a salty, metallic, bloody taste and a sweet aroma resembling serum.” Additionally MacLeod and Ames (1986) reported that even after heating ground fillet steak in a skillet for 1 min at 104°C, no meaty aromas were present. But after heating at 171°C, numerous “meaty” aromas were noted. This, of course, indicates that heating meat is required to produce the meaty, beefy aromas normally found in cooked meat.

LIPID THERMAL DEGRADATION

The thermal breakdown of lipids can best be described as the disassembly of neutral (triglycerides) and polar (phospholipids) lipids due to the change in energy stabilization during the heating process. It is generally recognized that disassembly favors shorter fatty acid chains and less saturation. Furthermore, triglycerides under thermal degradation form diglycerides, monoglycerides, and glycerol with no preference in the order of fatty acid position on the glycerol backbone. In general, the polar lipids are favored for degradation over the neutral lipids due to their higher degree of unsaturation as well as the absence of a fatty acid on the third carbon, giving rise to easier degradation. Recently, fatty acids of the polar lipid fraction were reported to be changed greatly by cooking, in comparison with neutral lipids (Legako, Dinh, Miller, & Brooks, 2015b). Nawar (1969) reported that when triglycerides were heated, shorter-chain fatty acids were released at a much greater incidence than long-chain fatty acids. It was suggested that shorter chain fatty acids are favored due to their higher solubility in water. This suggests that because the release of fatty acids from the glycerol chain is dependent on the amount of heat and composition of length and degree of unsaturation, the amount of heating would directly affect the quantity of volatile fatty acid products and therefore the flavor.

Much of that early work (Hornstein and Crowe, 1960; Kramlich and Pearson, 1960; Macy et al., 1964; Wasserman and Gray, 1965) suggested that the products of lipid degradation during cooking is responsible for species flavor largely based on the fact that the composition of fatty acids were very unique to each species. It also is suggested that the lean tissue is responsible for the ‘meaty’ flavor found in all species, but it is also important to remember that all lean tissue contains the phospholipid fraction in the cell membrane that house unique fatty acids. These polar lipids make up a very small proportion of the total lipid in beef. Furthermore, as beef neutral lipid content increases polar lipid proportion is decreased in turn (Legako et al., 2015b; Figure 1). However, despite their low proportion, in comparison with neutral lipids, polar lipids are extremely important to the formation of flavor components. Therefore, it is difficult to solely attribute species
flavors to adipose tissue alone, but instead to understand the complex nature of flavor development and the overlap of lipid and water-soluble compounds and their contribution to flavor.

The simplest products of lipid degradation result from the modification of fatty acids upon their removal from the glycerol backbone. These primary degradation products tend to be fairly simple compounds that bear resemblance to the fatty acid from which they are derived. As Mottram (1998) described, the most basic volatile compounds are aliphatic hydrocarbons, aldehydes, ketones, alcohols, carboxylic acids and esters. While most of these exist as simple straight-chain compounds, it is important to know that some aromatic (cyclical structure) compounds have also been reported as well as oxygenated heterocyclic compounds such as lactones and alkylfurans.

The products of thermal lipid degradation are very similar to those of lipid oxidation that occurs during long-term storage under oxidizing conditions (Mottram, 1998; 1985). The compounds, their composition, and the resulting aromas in oxidized meat tend to be described as having negative, rancid, off-flavor aroma descriptors, while those derived from thermal degradation during the cooking process are described as being very favorable and characteristic of cooked beef. In cooked beef, these chemical reactions occur much more rapidly and the different profile or composition of volatiles contributes to the desirable aromas. It is important to remember that, even if meat is cooked without any subcutaneous, intermuscular, or intramuscular fat, the volatile compounds derived from lipids are quantitatively dominant.

One of the most important concepts to understand in discussing volatile compounds is the aroma and (or) flavor threshold (Grosch, 1994). This is the minimum concentration that the volatile compound can be detected and usually is measured in parts per million (ppm) or parts per billion (ppb) of the compound dissolved in water. Because meat is about 75% water, this is a very useful measurement and helps us to more fully describe and understand how each of these volatiles contribute to the overall flavor of meat. In general, lipid-derived volatile compounds have higher thresholds than those for sulfur- and nitrogen-containing heterocyclic compounds in beef volatiles derived from the Maillard reaction. This means that more of the compound, or a higher concentration, is required for the human nose to detect its presence as an aroma. This also means that more of the lipid-derived compounds have to be produced in order to be detected (Czerny et al., 2008). The greatest quantity of these compounds include saturated and unsaturated aldehydes with 6 to 10 carbons. Generally, hexanal is the most common volatile compound found in fresh, cooked beef (Nawar, 1969). With oleic acid being the most abundant fatty acid and omega-6 fatty acids making up about 20% of phos-

![Figure 1. Percentages of neutral (NL) and polar (PL) lipid fractions (LF) of raw and cooked Prime, Low Choice, and Standard Longissimus lumborum steaks (n = 8). Overall effects of USDA quality grade and cooking were observed (P < 0.001) (From Legako, Dinh, Miller, & Brooks, 2015b).](image-url)
phospholipids, nonanal and hexanal are two very common fatty acids in beef. Heptanal, pentanal, and 2,4-decadienal also are significant contributors.

MAILLARD REACTION PRODUCTS

The Maillard reaction is a type of non-enzymatic browning of great interest to food scientists (Thorpe and Baynes, 2003). The reaction that involves carbonyl groups with free amino acids is most often associated with the browning that takes place when beef is cooked at higher temperatures. However, browning can also occur at room or refrigerated temperatures such as when dehydrated foods darken and develop off-flavors. Additionally, although browning is a trademark found during the Maillard reaction, it should not be confused with the caramelization of sugar during heating in the absence of amino acids. According to Nursten (1980) the significance of the Maillard reaction for food includes the production of color, the production of flavor and off-flavor, a reduction in nutritional value, possible toxicity through the potential formation of imidazoles and nitroso-derivatives, and finally the formation of antioxidant properties.

Unlike protein-derived volatile compounds, the lipid-degradation products contain only carbon, hydrogen, and oxygen, as these are the only elements present in lipids that play a part in volatile compounds. The main reaction in Maillard products involves the breakdown of proteins in beef when in the presence of a ‘reducing’ sugar. The two primary elements derived from protein, other than the carbon, hydrogen and oxygen also found in the lipids, are nitrogen from the peptide backbone, and sulfur from the side chains of amino acids, which are the building blocks of proteins. Fortunately, a reducing sugar, ribose, is available in close proximity to the proteins in the form of DNA and RNA as these contain deoxyribose or ribose in the nucleic acids, respectively. The first step in the Maillard reaction is the removal of water, or a dehydration reaction. This further reinforces the need of a dry atmosphere to catalyze the first reaction to take place. Associated with the Maillard reaction is Strecker degradation of amino acids by dicarbonyl compounds formed in the Maillard reaction (Thorpe and Baynes, 2003). The amino acid is decarboxylated and deaminated forming an aldehyde while the dicarbonyl is converted to an aminoketone or aminoalcohol. If the amino acid is cysteine, Strecker degradation can also lead to the production of hydrogen sulfide, ammonia, and acetaldehyde. These lead to a rich source of intermediates of many important classes of flavor compounds including furans (contains O), pyrazines (contains N), pyroles (contains N), oxazoles (contains N), thiophenes (contains S), thiazoles (contains S) and other heterocyclic compounds. The Maillard and related reactions are extraordinarily complex and contribute a myriad of compounds involved in the flavors, which are generally described as roasted, browned, meaty, caramelized and more.

LIPID-MAILLARD INTERACTIONS

Shahidi (2004) described how the aldehydes that were generated during thermal lipid degradation can participate in the Maillard reaction at both the initial and later stages of thermal processing. Volatile pyridines, pyrazines, thiophenes, thiazoles and oxazoles with alkyl side chains can be formed. Several thiazoles with four- to eight-carbon alkyl substituents in the two position have been reported in roast beef, and other alkylthiazoles with longer alkyl chains have been identified in the volatiles of heated beef. In general, volatile compounds from lipid-Maillard interactions have weak odor intensities and higher odor thresholds compared to those generated in each of the primary reactions. Moreover, volatiles produced in the interaction of these two systems may have indirect impacts on the generation of volatile flavor compounds. In particular, Shahidi (2004) reported that phospholipids and their degradation products inhibit important reactions involved in the formation of heterocyclic aroma compounds in the Maillard reaction. Therefore, the generation of sulfur-containing heterocyclics during thermal processing of beef may be reduced by this inhibition. Interestingly, this inhibition may help to maintain reasonable levels of many of the sulfur compounds that may have malodors at higher concentrations, and thereby contribute to a balanced generation of complex aroma and flavor notes.

RELATIONSHIPS OF VOLATILE COMPOUNDS WITH SENSORY EVALUATION

Beef flavor is certainly not a new area of study. However, many past studies were conducted to determine flavor development pathways by model systems or to characterize individual beef compounds through olfactometry. Relating volatile compounds from cooked beef steaks with consumer or trained panelist ratings is challenging, but may be a means to better understand beef flavor. Previous research regarding differences in flavor among muscles has focused on flavor intensity and the presence of off-flavors. Calkins and Hodgen (2007) have summarized muscle rankings based on flavor intensity and off-flavors. In most cases flavor intensity and off-flavors were correlated with each other. Volatile compounds associated with lipid oxidation have been reported to vary between muscles of the chuck and round influencing perceived flavor (Hodgen, Cuppett, & Calkins, 2006). In support of these findings, recent work has revealed volatile aldehydes, nonanal and decanal, were negatively correlated with consumer flavor liking (Legako et al., 2015a).

To further explore relationships between volatile compounds and sensory data multivariate statistical packages are often utilized. Principal component analysis (PCA) has revealed that volatile compounds segregated into clusters of similar compound classes (Legako et al., 2015a; Figure 2). This collinear divergence of compound groups present the opportunity to utilize compound groups as a
Figure 2. Principal component (PC) analysis for volatile compounds, of five USDA quality grades (Prime = PR, Upper 2/3 Choice = HC, Low Choice = LC, Select = SL, Standard = ST) and four muscles (Psoas major = PM, Longissimus lumborum = LL, Gluteus medius = GM, Semimembranosus = SM). Volatile compound groups shown with different formatting: Maillard products and lipid oxidation products. Consumer palatability traits and proximate data (%) were correlated on the same axes (From Legako, Brooks, O’Quinn, Hagan, Polkinghorne, Farmer, & Miller, 2015a).
means to explore flavor relationships. Furthermore, flavor compounds with very low detection level but great odor significance may be represented through measurement of similar compounds. Previously, Maillard products were closely associated with flavor development (Mottram, 1998). The importance of Maillard products appear to be realized through PCA, where Maillard reaction products are more related with consumer flavor liking compared with other compound groups (Legako et al., 2015a).

**CONCLUSIONS**

Flavor development is primarily dependent on two factors: reactant mixture and reaction conditions. Reactant mixture refers to the precursors of flavor, i.e. fatty acids, amino acids, reducing-sugars, nucleotides, and etc. Reaction conditions refer to the thermal kinetics as a result of varied time and temperature exposure (cooking). Flavor development, therefore, is highly dependent on the reactant mixture (precursor compounds) and reaction conditions (cooking). Volatile compounds are the final products of cooked beef flavor development. Measurement of volatile compounds presents an opportunity to understand beef flavor development and how chemical flavor components relate with perceived flavor by consumers and trained panelists.

**LITERATURE CITED**


Grosch, W. 1994. Determination of potent odourants in foods by aroma extract dilution analysis (AEDA) and calculation of odour activity values (OAVs). Flav. And Frag. Jour. 9:147-158.


