



*The Chemistry of
Beef Flavor
Executive Summary*



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The Chemistry of Beef Flavor - Executive Summary

Prepared for the National Cattlemen's Beef Association

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The beef industry is continually working to satisfy consumer expectations for dependable, high quality beef products at a reasonable cost to producer, packer, processor and retailer. Flavor and tenderness are the sensory traits that affect consumer acceptance of beef the most; therefore, it is vital that both traditional and new beef systems assure consistently tender products with acceptable flavor.

– Kerth et al., 1995



“Flavor”

results from the combination of basic tastes (sweet, sour, bitter, salt and umami) derived from water-soluble compounds and odor derived from a myriad of substances present in the food product from the onset or derived via various reactions. The flavors and aromas associated with beef are generally those that develop during heating. When water-soluble substances derived from precursor compounds dissolve in the saliva, they bind to the taste buds and stimulate a response that is perceived in the brain. Odor occurs when volatile compounds bind to receptors in the olfactory bulb behind the nasal cavity and stimulate a response. Both flavor and odor release depend on the matrix in which they are embedded, therefore, texture has a tertiary effect on both because it modulates when they are available to be perceived.

A wide array of flavor-active volatiles occur in beef (acids, alcohols, aldehydes, aromatic compounds, esters, ethers, furans, hydrocarbons, ketones, lactones, pyrazines, pyridines, pyrroles, sulfides, thiazoles, thiophenes; Shahidi, 1994). The relationship

between some of the more common volatiles in beef and their respective flavors is shown in Table 1. Beef flavor, which develops when heat is applied, depends on the amounts and proportions of precursor compounds present. Meat is composed of water, proteins, lipids, carbohydrates, minerals and vitamins. Of these, proteins, lipids and carbohydrates play primary roles in flavor development because they include numerous compounds which are capable of developing into important flavor precursors when heated (Spanier and Miller, 1993; Mottram, 1998). The compounds that elicit various tastes and odors have different thresholds for perception (Wasserman, 1979).

Sweet flavor in meat is derived from sugars, amino acids and organic acids (Table 1). Sour flavors arise from amino acids coupled with organic acids. Inorganic salts and sodium salts of glutamate and aspartate generate saltiness. Bitterness is likely due to hypoxanthine, anserine and carnosine as well as some amino acids (MacLeod, 1994).

Amino acids and peptides, derived from proteins, give rise to compounds such as ammonia, aldehydes and amino ketones.

Table 1. Flavors and aromas associated with volatile compounds in beef.

Compound	Flavors Aromas	Compound	Flavors Aromas
Pentanal	Pungent	2-methyl-3-[methylthio]furan	Meaty, sweet, sulfurous
Hexanal	Green, grassy, fatty	4-hydroxy-5-methyl-3(2H)-furanone (HMF)	Meaty
Heptanal	Green, fatty, oily	Methylpyrazine, 2,5- (and 2,6-) dimethylpyrazine	Roasted, nutty
Nonanal	Soapy	Pyrazines	Nutty, cracker-like, bell pepper
Methional	Cooked potato	Amino acids: glycine, alanine, lysine, cysteine, methionine, glutamine, succinic	Sweet
12-methyltridecanal	Beefy	Organic acids: lactic, inosinic, ortho-phosphoric, and pyrrolidone carboxylic	Sweet
Nona-2(E)-enal	Tallowy, fatty	Sugars: glucose, fructose, ribose	Sweet
Deca-2(E), 4(E)-dienal	Fatty, fried potato	Amino acids: aspartic acid, histidine, asparagines	Sour
Butanoic Acid	Rancid	Organic acids: succinic, lactic, inosinic, ortho-phosphoric, pyrrolidone carboxylic	Sour
Hexanoic Acid	Sweaty	Hypoxanthine, anserine, carnosine	Bitter
Delta-nonalactone	Sweet, dairy, or waxy notes	Amino acids: arginine, leucine, tryptophan	Bitter
Decan-2-one	Musty, fruity	Monosodium glutamate (MSG), inosine and guanosine monophosphate (IMP,GMP)	Savory, brothy, beefy
3-Hydroxy-2-butanone	Buttery	Bis(2-methyl-3-furyl) disulfide	Roasted meat
2,3-Octanedione	Warmed over flavor, lipid oxidation	2-methyl-3-furanthiol	Roasted meat
1-Octene-3-ol	Mushroom		
2-Pentyl furan	Metallic, green, earthy, beany		

Sources: Gasser and Grosch, 1988; Spanier and Miller, 1993; Mottram, 1998; Shahidi, 1998; MacLeod, 1994; Spanier et al., 1992; Guth and Grosch, 1993; MacLeod and Ames, 1986; Rowe, 2002; Ha and Lindsay, 1991; Maga, 1994.

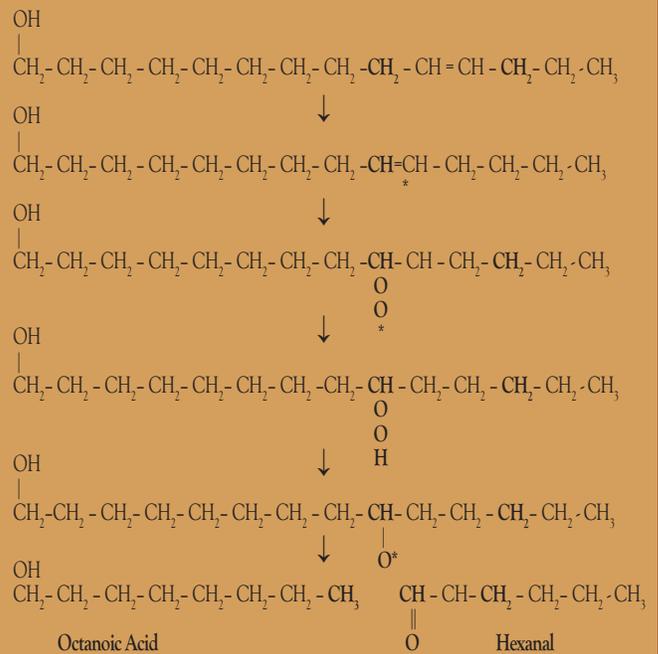
Sulfur-containing amino acids generate hydrogen sulfide and methane thiol which contribute to general meaty and onion-like flavors and have low detection thresholds, especially in boiled meats (Mottram, 1998). Nucleotides produce furanones which have a meaty flavor (Spanier et al., 2004).

Umami is taste described as savory, brothy or beefy. It is produced by flavor-potentiating compounds, such as MSG (monosodium glutamate), IMP (5-nucleotides, 5'-inosine monophosphate) and GMP (5'-guanosine monophosphate). Umami layers flavors allowing perception of different flavors to occur at different times; the layers then combine to create a full flavor (Marcus, 2005). In addition, the 8 amino acid "Beefy Meaty Peptide" (BMP; Lys-Gly-Asp-Glu-Glu-Ser-Leu-Ala) exhibits umami characteristics (Yamasaki and Maekawa, 1978). This peptide may be found naturally in meat and has flavor properties analogous to MSG without the perceived added saltiness (Spanier et al., 1992).

Lipids are a source of flavor constituents, both directly (unmodified) and indirectly (reaction products). The lipids present in meat (subcutaneous fat, intramuscular fat, intermuscular fat, intramyocellular lipid and structural phospholipids) are composed of fatty acids that may be saturated, unsaturated and/or methyl-branched (Figure 1). Oxidation of unsaturated fatty acids typically produces a variety of volatile compounds, some of which give the characteristic odors to specific types of meat (Figure 2). Phospholipids make up approximately 0.5-1% of the lean tissue (primarily phosphoglycerides) and contain a high proportion of unsaturated fatty acids that are susceptible to oxidation and likely to make specific flavor contributions (Mottram, 1998). They are also the source of several sulfides generated when they react with cysteine and/or ribose to produce mild, slightly beefy compounds (2-methyl-3-[methylthio]thiophene; Rowe, 2002).

acids induces oxidation producing intermediate hydroperoxides that decompose via free radical mechanisms eventually resulting in aldehydes, unsaturated alcohols, ketones and lactones, which have relatively low detection thresholds (Figure 1 and Table 1; Mottram, 1998). Aldehydes, in particular, have meaty, tallowy odors (Rowe, 2002). Carbohydrates give rise to furans which react with the sulfur-containing amino acid cysteine to yield roasted meat aromas (Hogan, 2002). They can also produce lactones that may have sweet, dairy or waxy notes (delta-nonalactone).

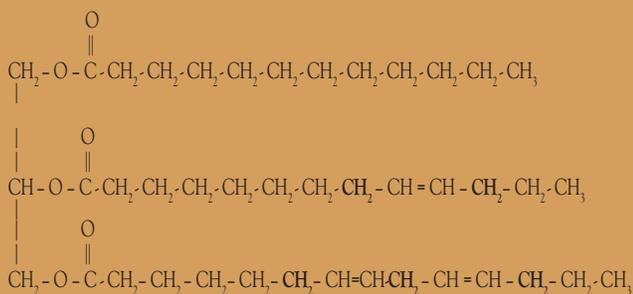
Figure 2. Oxidation of unsaturated fatty acid



"Meaty flavor", the generic background flavor of all types of red meat, is often associated with the lean portion of meat. More than 60 compounds have been identified that contribute specifically to "meaty" aromas (Shahidi, 1998). The compounds in the volatile fraction of meat that possess "meaty aroma" characteristics are mostly sulfur- or carbonyl-containing compounds (Hogan, 2002). Low levels of sulfur-containing compounds are meaty; however, high levels are objectionable.

Water-soluble compounds appear to be of primary importance in meat flavor. Aroma appears to be the most important contributor to the identification of the species of animal from which meat is derived (Matsuishi et al., 2006) while taste makes a much smaller contribution. "Species-specific flavor" may result from quantitative differences of the same compounds (3,5-dimethyl-1,2,4, trithiolane, 2,4,6-trimethylperhydro-1,3,5-dithiazine, mercaptothiophenes or mercaptofurans; Shahidi et al. 1994). Species-specific flavor has traditionally been associated with the lipid portion because more than 650 fat-soluble volatiles are released when beef is heated (Shahidi, 1994; MacLeod, 1994).

Figure 1. Triglyceride with saturated mono-unsaturated and poly-unsaturated fatty acids



Raw meat has little aroma and only a blood-like taste; however, it is a reservoir of compounds that serve as aroma and flavor precursors (Shahidi, 1994). Meat flavor is thermally derived and consists of "meaty flavor" and "species-specific flavor." Heating unsaturated fatty

The impact of fat from various species on flavor/aroma of cooked products is unclear. Cross et al. (1980) found no differences in ground beef flavor intensity regardless of fat content (16 to 28%) while El-Magoli et al. (1996) reported that increasing fat level (from 11 to 22%) increased 2-butanone, 2-pentanone and 3-hydroxy-2-butanone. Mottram (1998) reported that inclusion of 10% fat from either beef or pork into ground lean enabled panelists to distinguish between species. Mottram et al. (1982), profiling volatiles from combinations of beef and pork lean with beef and pork fat, found that any sample containing a beef constituent (lean or fat) contained an alkene that contributed a damp, soapy note when its odor was evaluated individually.

Beef also contains larger amounts of alcohols (mostly 1-pentanol, 1-octen-ol, and 1-heptanol) and aromatics (1,2-dimethylbenzene) and less benzaldehyde and decanal than pork. A distinctly beef-like aroma compound, 12-methyltridecanal, has been identified as an important constituent to species flavor; it occurs only in small amounts in other species. Other antesisio-methyl-branched compounds

identified are believed to arise from phosphoglycerides (Mottram, 1998; Werkoff et al., 1996). Phospholipids from lean muscle may contribute the majority of important species-specific flavor volatiles in beef implying that species flavor may not be based on the neutral fat (triglyceride) portion of meat alone.

The impact of marbling on beef flavor is of significant interest. Increased marbling, because of the increased amount of fat available for formation of flavor compounds, has traditionally been considered to have a relatively large impact on beef flavor. However, adding beef fat to beef lean does not give a proportional increase in lipid derived volatiles (Mottram et al., 1982; Cross et al., 1980) indicating that the lipids in the lean (phospholipids) are the source of some of these compounds.

It is important to understand what roles diet, processing (and enhancement) and cooking have on flavor constituents. Water soluble flavor precursors (e.g. free amino acids) and taste-active compounds may be equally important from an overall flavor impact standpoint.



Effect of Breed on Beef Flavor

Beef flavor can be affected by the breed of cattle from which the meat is derived. Nitrogen- and sulfur-compounds, free amino acids, alcohols, aldehydes and ketones in the flavor volatiles differ among beef from different breeds of cattle (Sato et al., 1995; Insausti et al., 2005). Beef from Friesian cattle has a stronger fatty flavor and aftertaste, and a different volatile profile than that from Pirenaica cattle (Gorraiz et al., 2002). Hamburgers made from lean and fat derived from Wagyu cattle have better sensory quality than those made with fat from dairy cattle. The former yield more volatile compounds and higher concentrations of volatile

acids, ketones and lactones. Samples made with dairy beef fat have relatively high contents of aldehydes and alcohols (Sato et al., 1995).

Casas et al. (2006) recently reported that in *Bos taurus* and *Bos indicus* breeds, including crossbred animals from Hereford, Angus, Brangus, Beefmaster, Bonsmara and Romosinuano, markers at the calpastatin and μ -calpain genes are associated with flavor intensity. Animals inheriting the CC genotype at the calpastatin gene and the TT genotype at the μ -calpain gene produce steaks with an intense flavor when compared with the other genotypes.



Effect of Diet on Beef Flavor

High-energy grain diets produce a more acceptable, more intense flavor in red meats than low-energy forage or grass diets (Melton, 1990). Grain feeding generally increases carcass weight and intramuscular fat content compared with forage feeding. More than 40% of the variation in beef flavor between grass- and grain-finished beef, unaged and aged beef has been accounted for by diet (Bruce et al., 2005). More linolenic acid and less oleic and linoleic acids in forage-fed beef compared with concentrate-fed beef may be partially responsible for these diet differences (Elmore et al., 2004). Steaks from pasture-fed cattle finished on corn contain less acetic and caproic acids and equal amounts of several other fatty acids (propionic, isobutyric, butyric, isovaleric, valeric, isocaproic and heptanoic; Yeo, 1983) than those maintained on pasture alone.

Phospholipid and fatty acid composition of the phospholipids are correlated with flavor differences in ground beef. Phospholipid and fatty acid contents increase with time on feed beyond the initial forage grazing period (Larick et al., 1989). When steers are fed grain, gamey/stale off-flavor decreases and roasted beef flavor increases (Maruri and Larick, 1992). This may be due to increases in the phospholipids, phosphatidylcholine and phosphatidylethanolamine. Diterpenoids correlate with gamey/stale off-flavor and with loss of roasted beef flavor; lactones correlate with roasted beef flavor and with lower gamey/stale off-flavors. Grassy flavor of steaks and ground beef decreases when pasture-fed steers are grain-fed ad libitum (McMillin et al., 1991). Grassy flavor increases as low molecular weight alkanols, alkenals, acids (C7 to C10) and various C20 hydrocarbons increase, while lactones decrease.

Meat from steers grazed on fescue pasture has a grassy, bitter and cow-like flavor (Hedrick et al., 1980). Cooked fat flavor and aroma are more intense than that from lean. This may be due to the compounds methylbenzaldehyde, naphthalene and 2,4-decadienal. Ground beef from steers wintered on pasture/hay has less desirable flavor and beef fat flavor, more dairy-milky flavor and usually soured dairy or other off-flavors compared with beef from grain-finished steers; it also has the highest percentage of C18:3 in the neutral and polar lipids (Melton et al., 1990). Particularly odorous compounds include aldehydes (4-heptenal (and/or heptanal), 1-Octene-3-ol, Nonanal and 2,6-nonadienal).

Diets containing fish by-products, raw soybeans or canola oil and meal can cause undesirable flavors in beef (Melton, 1990). The increase in unsaturated fatty acids may be to blame because they increase oxidation during storage. Palm-oil and whole linseed supplements increase muscle levels of alpha-linolenic [C18:3] and EPA (eicosapentaenoic acid [C20:5]); fish oil increases EPA and DHA (docosahexaenoic acid [C22:6]; Elmore et al., 2004). These compounds oxidize readily and can increase alkanals four-fold in the aroma extracts from steaks. Cooked beef from animals fed lipid supplements high in n-3 polyunsaturated fatty acids contain higher levels of 2-alkyl-(2H)-thiapyrans and 2-alkylthiophenes in the volatiles (Elmore and Mottram, 2000). While thiapyrans have low odor potency, the reactions that form them may remove potent aroma compounds which modify meat aroma profile. The net effect is that positive attributes, such as beef flavor, decrease whereas negative attributes, such as rancid flavors, increase.



Effect of Aging on Beef Flavor

Aging improves tenderness (Gruber et al., 2006), but questions remain concerning the effects of aging on flavor (Mottram, 1998). To the extent that aging alters the make-up of the aroma and flavor precursors of beef flavor, it can affect the sensory characteristics of the cooked product.

Unaged beef has a weak, bland odor while aged beef has a strong, savory, roasted odor. Aging up to 14 days increases fatty flavor and positive flavor notes such as “beefy”, “brothy”, “sweet” and “browned caramel” and some negative attributes such as “painty”, “cardboard”, “bitter” and “sour” (Spanier et al., 1997; Gorraiz et al., 2002; Bruce et al., 2005). Stetzer et al. (2006a,b) reported that positive flavor compounds decrease with aging and negative compounds increase (Figures 3 and 4). Pentanal and 3-hydroxy-2-butanone decrease while nonanal, butanoic acid and 1-Octene-3-ol increase.

After harvest, loss of circulatory competency results in the accumulation of metabolic by-products, including lactic acid, in the muscle. Postmortem pH decline facilitates flavor changes. A number of endogenous enzymes (cathepsins B and L) are activated near pH 5.4. These thiol proteinases, which can hydrolyze more peptide bonds than any other group of enzymes, are redistributed (intracellularly) during aging (Spanier and Miller, 1993; Spanier et al., 1990). Proteolytic enzyme activity is temperature-dependent; some enzymes (cathepsins B and L) retain high activity levels even at cooking temperatures (70°C). The combined effect of postmortem aging and cooking, via enzyme redistribution and activity, can influence the production of flavor compounds. Enzymes known primarily for textural

changes (μ - and m-calpain) during the postmortem period influence flavor by producing peptides. These enzymes correlate with increases in rancid, sour and salty flavors (Toldrá and Flores, 2000).

Aging increases carbonyls derived from lipid oxidation, some of which may contribute noticeable off-flavors. Aging for >21 days may decrease flavor identity; aging for 35 days may increase metallic flavor (Yancey et al., 2005). Changes in umami taste also occur during aging. Glutamic acid content more than doubles during the first 7 days of aging (from 9 mg/100g at 4 days to 21 mg/100g at 7 days; Bauer, 1983). In addition, microbial activity during aging can hydrolyze protein liberating free glutamic acid. Microbial degradation of lipids into flavor precursors should not be ruled out as a significant effect of the aging process.

Carcass infusion prior to aging affects palatability. Infusion with vitamins C, E or C plus E has little effect on the flavor of either freshly cooked or warmed-over steaks (Yancey et al., 2002). However, calcium chloride (CaCl₂) reduces beef flavor identification, brown-roasted flavor and bloody/serummy flavor and increases soapy/chemical flavor in both (Carr et al., 2004).

The conditions (oxygen availability, temperature, humidity and aging time) under which beef is aged affects the ultimate flavor of the meat. Aging in a higher oxygen environment results in a burnt, toasted off-odor. Derivatives of 2-methyl-3-furanthiol provide a more aged beef aroma (Rowe, 2002). In addition, dry-aging increases beef flavor more than aging in vacuum or in carbon dioxide (Campbell et al., 2001; Sitz et al., 2006; Jeremiah and Gibson, 2003).

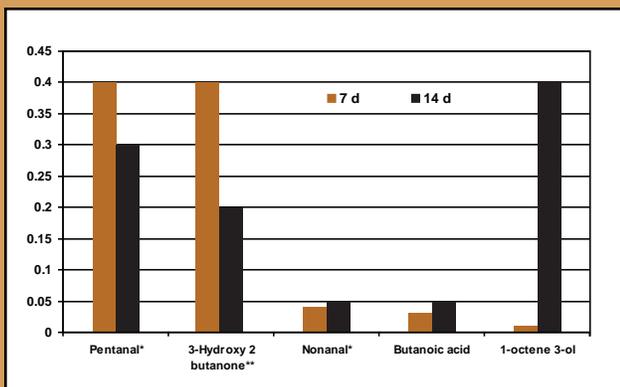


Figure 3. Effect of aging on volatiles (µg) in beef (*) *Gluteus medius* (sirloin), *Infraspinatus* (chuck), *Psoas major* (loin), *Rectus femoris* (round), *Teres major* (chuck) and (**) *Complexus* (chuck), *Serratus ventralis* (rib), *Vastus lateralis* (round), *Vastus medialis* (round) and *Longissimus dorsi* (loin) muscles.

Source: Stetzer et al., 2006 a,b,c.

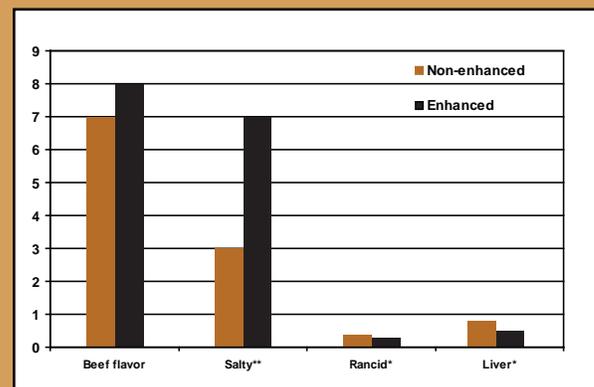


Figure 4. Effect of enhancement on sensory characteristics of beef (*) *Gluteus medius* (sirloin), *Infraspinatus* (chuck), *Psoas major* (loin), *Rectus femoris* (round), *Teres major* (chuck) and (**) *Complexus* (chuck), *Serratus ventralis* (rib), *Vastus lateralis* (round), *Vastus medialis* (round) and *Longissimus dorsi* (loin) muscles.

Source: Stetzer et al., 2006 a,b,c.

Effect of Enhancement on Beef Flavor

Brine injection, or enhancement, improves the sensory quality of beef (Vote et al., 2000; Molina et al., 2005; Baublits et al., 2006a,b). Enhancement solutions contain, at the minimum, some form of phosphate to retain added fluid and salt to enhance flavor and retain fluid. The pH of enhanced meat may increase slightly depending on the type of phosphate utilized. Enhancement solutions may also contain flavor enhancers (sodium and/or potassium lactate) or organic acids (sodium diacetate) which extend shelf-life by suppressing microbial growth, and flavoring ingredients (beef broth). Enhancement generally ranges from 6% to 12% of initial weight. Higher concentrations of added ingredients can create off-flavors (Seyfert et al., 2005).

Salt enhances flavor but is a known prooxidant. Phosphates can chelate iron making it unavailable to catalyze lipid oxidation, suppressing off-flavor development. Enhanced beef is saltier, more intensely beef flavored and has less off-flavor and beany/grassy aroma than non-enhanced beef (Robbins et al., 2003); however, enhanced beef may exhibit atypical flavors (Hoffman, 2006). The salt in the enhancement solution impacts flavor by increasing saltiness and beef flavor while masking off-flavors.

Hexametaphosphate, sodium tripolyphosphate and tetrasodium pyrophosphate are commonly used at 0.2% to

0.4% of final product weight. Sodium salts of tripolyphosphate increase meaty flavor and decrease stale and rancid flavor/aroma and hexanal during storage; however, they can produce a soapy aftertaste (Vote et al., 2000). Beef enhanced with a phosphate-containing solution can be reheated after refrigerated storage with minimal flavor loss (Robbins et al., 2003). In general, enhancement increases beef flavor slightly and saltiness dramatically, and decreases rancid off-flavor, hexanal, hexanoic acid and 1-Octene-3-ol (Stetzer et al., 2006; Figures 4 and 5).

Enhancement affects sensory characteristics of different muscles differently (Stetzer et al., 2006a,b,c; Figures 6 and 7). It decreases the liver off-flavor of the *Psoas major* (loin) and the *Gluteus medius* (round) the most (60% and 50%, respectively) but affects the *Teres major* (chuck) much less (<17%).

Sodium lactate is often used as a flavor enhancer because it increases both beefy and meaty flavors. Positive fresh flavor notes are higher, flavor profiles do not change during storage and warmed-over flavor is minimized by sodium lactate addition (Robbins et al., 2002; 2003).

Calcium lactate injection after rigor mortis improves tenderness but results in flavor defects similar to those resulting from calcium chloride decreasing beef flavor and increasing off-flavor scores; however, this effect is inconsistent (Got et al., 1996; Lansdell et al., 1995). Injecting phosphate, lactate or chloride solutions does improve beef flavor (Vote et al., 2000).

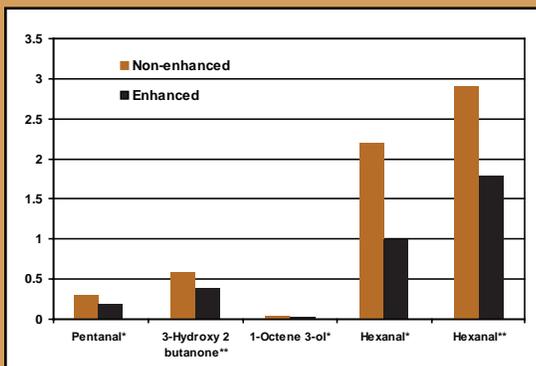


Figure 5. Effect of enhancement on volatiles (µg) in beef (*) *Gluteus medius* (sirloin), *Infraspinatus* (chuck), *Psoas major* (loin), *Rectus femoris* (round), *Teres major* (chuck) and (**) *Complexus* (chuck), *Serratus ventralis* (rib), *Vastus lateralis* (round), *Vastus medialis* (round) and *Longissimus dorsi* (loin) muscles.

Source: Stetzer et al., 2006 a,b,c.

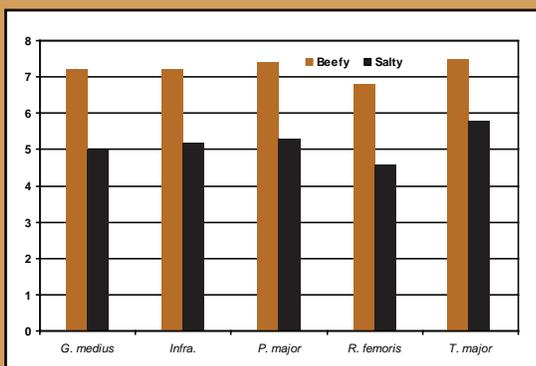


Figure 6. Sensory characteristics of beef *Gluteus medius* (sirloin), *Infraspinatus* (chuck), *Psoas major* (loin), *Rectus femoris* (round) and *Teres major* (chuck) muscles.

Source: Stetzer et al., 2006 a,b,c.

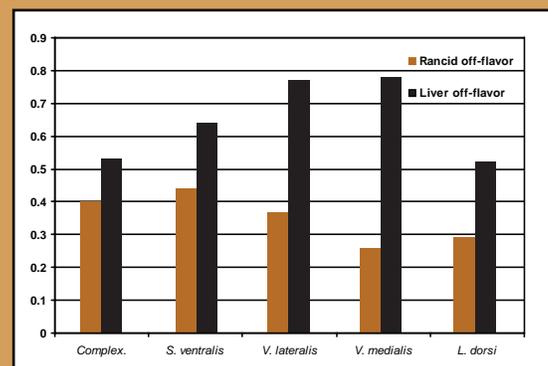


Figure 7. Sensory characteristics of beef *Complexus* (chuck), *Serratus ventralis* (rib), *Vastus lateralis* (round), *Vastus medialis* (round) and *Longissimus dorsi* (loin) muscles.

Source: Stetzer et al., 2006 a,b,c.

Effect of Heat on Beef Flavor Development

Although cooked meat flavor is influenced by water-soluble components that contribute to taste, it is the volatile compounds formed during cooking that produce the aroma attributes that contribute the characteristic flavors of meat. Based on sensory evaluation, eight general odor qualities (buttery, caramel, burnt, green, fragrant, oily/fatty, nutty and meaty) have been used to describe cooked meat odor. Components associated with the seven former qualities are aroma modifiers, while those contributing meaty quality (2-methyl-3-[methyl]-furan, 3-methylcyclopentanone) are character impact compounds. At least seventeen compounds specifically contribute to the aroma of cooked beef. Seven (bis[2-methyl-3-furyl]disulfide, methional, 4-ethyl-1-methylhexane, 1,1,3-trimethylcyclohexane, alpha-pinene, 4-ethyl-1,2-dimethylbenzene, and 3,6-dimethylundecane) are unique to beef (Narasimhan-Ramarathnam et al., 1993; Imafidon and Spanier, 1994).

Heating (cooking) also develops flavor via the browning (Maillard) reaction. Initially, an amino compound (NH_2 from a protein or peptide) and the carbonyl group ($-\text{HC}=\text{O}$) of a reducing sugar condense to form an aldehyde and an aminoketone. Rearrangement and dehydration form furfural and furanones, hydroxyketones and dicarbonyl compounds.

Degradation of sulfur-containing amino acids (cysteine and/or methionine) provides sulfur that contributes to this process. These amino acids can produce hydrogen sulfide (H_2S) and ammonia (NH_3), some of the most pungent aromatic compounds generated during cooking (Mottram, 1998). These compounds can react with amines and amino acids to produce a number of flavor-contributing compounds and potent cooked beef odorants (pyrazines, oxazoles, thiophenes, thiazoles and other heterocyclic

sulfur containing compounds; Mottram, 1998; Guth and Grosch, 1993; MacLeod and Ames, 1986).

Mixing hydrogen sulfide (H_2S) with furanones (4-hydroxy-5-methyl-3(2H)-furanone [HMF] and 2,5-dimethyl-4-hydroxy-(2H)furan-3-one) produces a distinctly meaty flavor (Ouweland et al., 1975). Cooking temperatures and methods affect these

reactions. Heating at lower temperatures ($<165^\circ\text{C}$) versus higher temperatures ($>180^\circ\text{C}$) results in differences in the concentrations of a number of compounds (2,4-dimethyl-3-oxazoline; 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; Mussinan et al., 1975).

A strong relationship exists between cooking temperature, concentration of free amino acids, carnosine, IMP, pyrazines and hexanol, and roasted, burnt and beefy flavor intensity (Lorenzen et al., 2005; Cambero et al., 1992).

Heating beef generates urea which can also reduce sulfur-containing compounds generating important nitrogen-containing volatiles (pyrazines and/or thiazoles). Pyrazines, formed mostly on the surface of meat,

have nutty, cracker-like or bell pepper aromas (Hogan, 2002). Thiazoles have green or fruity notes (Rowe, 2002). It may be that ammonia is released from urea upon heating, then competes with hydrogen sulfide to react with Maillard reaction precursors to produce nitrogen-containing compounds (alkylpyrazines; Yong et al., 2000).

In general, the higher the degree of heating, the higher the concentration of aliphatic aldehydes, benzenoids, polysulfides, heterocyclic compounds and lipid-derived volatiles. Ketones, alcohols (of non-lipid origin) and mono-sulfur components make smaller contributions. In addition, cooking appears to affect umami-related compounds by reducing free glutamate (Maga, 1998).



Differences in Flavor of Various Beef Muscles

The *Psoas major* (loin) and *Teres major* (chuck) had more intense beefy flavor than the *Rectus femoris* (round); however, the latter also had less off-flavor (Yancey et al., 2005; Stetzer et al., 2006a,b,c; Figure 6). The *Serratus ventralis* (rib) had the highest rancid off-flavor score and 3-Hydroxy-2-butanone content (Figures 7 and 8). The *Vastus lateralis* (round) and the *Vastus medialis* (round) had the highest liver off-flavor scores while the *Longissimus dorsi* (loin) and *Complexus* (chuck)

had the lowest. Hexanal was the volatile present in the largest amounts. The *Infraspinatus* (chuck) contained more than twice the amount of hexanal as the other muscles while the *Gluteus medius* (sirloin) contained the least (Figure 8). The *Gluteus medius* contained the most 3-hydroxy-2-butanone and the *Infraspinatus* contained the least. Hexanal is an indicator of lipid oxidation. Kukowski et al. (2004) reported that the *Triceps brachii* (chuck) is more flavorful than the *Longissimus thoracis* (loin), *Serratus ventralis* and *Complexus* and less flavorful than the *Supraspinatus* (chuck).

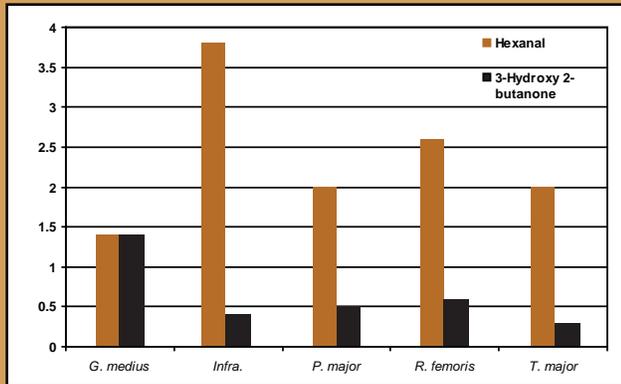


Figure 8. Volatiles (Hexanal and 3-Hydroxy 2-butanone; µg) in beef *Gluteus medius* (sirloin), *Infraspinatus* (chuck), *Psoas major* (loin), *Rectus femoris* (round) and *Teres major* (chuck) muscles.

Source: Stetzer et al., 2006 a,b,c.

Off-Flavor in Beef

Oxidation

of meat lipids damages both odor and flavor of fresh, cooked, stored (refrigerated or frozen) or reheated meat resulting in rancid and/or warmed over flavor. Lipid oxidation produces a variety of aldehydes (hexanal, heptanal, pentanal and 2, 4-decadienal; Figure 2) from phospholipids and polyunsaturated fatty acids, some of which have unpleasant odors at very low concentrations. Oxidation can be initiated by light, heat, metals (iron and copper), myoglobin (which contains iron) and some commonly used ingredients.

Salt is a known pro-oxidant at levels commonly used in processed meats (0.5-2.5%). A pro-oxidant is an ingredient or additive that accelerates oxidation of fats or oils resulting in rancidity. Oxidation increases with salt concentration in this range (Rhee and Ziprin, 2001). This trend is more apparent in red meat (beef) than white meat (chicken) (Rhee et al., 1996). Oxidation of frozen raw beef is higher than for chicken as is heme iron content. Heme iron facilitates lipid oxidation producing peroxides which are enzymatically decomposed by catalase producing a variety of compounds, some of which contribute off-flavors.

Cooking beef prior to storage (refrigerated or frozen) accelerates lipid oxidation and often precipitates warmed-over

flavor (WOF) which is described as a “stale”, “cardboard-like”, “painty” or “rancid” odor. WOF can develop in pre-cooked frozen meats in a few days; however, it is usually associated with cooked meat that has been refrigerated for 48 hours or less. WOF results from loss of desirable odorants (furanones) and an increase in lipid oxidation products (hexanal and/or decenal; Kerler and Grosch, 1996). The rate of decline in species-specific flavor intensity and the rate of increase in “cardboard” flavor intensity are fastest during the first three days of refrigerated storage (Rhee et al., 2005).

Storing beef in vacuum retards development of chemical markers of flavor deterioration (hexanal and/or pentanal); however, it only partially retards development of painty, cardboard, bitter and sour flavors and loss of desirable cooked beef/brothy and browned/caramel flavors (Spanier et al., 1992). Modified atmosphere packaging (MAP) maintains beef flavor if oxygen is excluded.

Heating beef fat in a nitrogen environment produces primarily aldehydes and ketones (ethanal, propanal, isobutanal, isopentanal, crotonal, benzaldehyde, acetone, methyl ethyl ketone, methyl isobutyl ketone, glyoxal and pyruvaldehyde) while heating in air produces primarily aldehydes (hexanal, heptanal, 2-heptenal, octanal, 2-octenal, nonanal, 2-nonenal, 2-decenal and 2, 4-

decadienal, 2-undecenal; Yamato et al., 1970). The total number of long-chain carbonyls is larger and the oily odor is stronger in beef fat heated in air than in nitrogen, also indicating that oxidation of fatty acids to carbonyl compounds contributes to off-odor and can be affected by gas atmosphere. Cooked, reheated beef flavor and aroma is more meaty, less warmed-over, cardboardy and oxidized in vacuum or N₂/CO₂ packages than that packaged in air (Hwang et al., 1990). Beef quality degrades during storage in high oxygen MAP; it is accompanied by an increase in 2, 3, 3-trimethylpentane, 2, 2, 5-trimethylhexane, 3-octene, 3-methyl-2-heptene, 2-octene, and 2-propanone and a decrease in dimethyl sulfide (Jayasingh et al., 2002; Insausti et al., 2002).

Livery flavor is an objectionable off-flavor sometimes associated with beef (Campo et al., 1999). It appears that sulfur-containing compounds, including thiols, sulfides, thiazoles and sulfur-substituted furans, interact with carbonyl compounds to produce the livery flavor attribute (Werkhoff et al., 1996). Higher concentrations of phospholipids, phosphatidylcholine and phosphatidylethanolamine increase livery and ammonia flavors in beef (Larick et al., 1989). Livery flavor also correlates with 16-, 17-, 18- and 20-carbon chain fatty acids (2-decenal, 2-undecenal, propanoic acid; vaccenic acid, cis-11, 14 eicosadienoic acid, 5,8,11,14,17-eicosapentaenoic acid; Yancy et al., 2006; Hodgen et al., 2006). Higher levels of heptanol, hexanal, hexanol, B-pinene, 1-octene-3-ol, Nonanal and cyclotetrasiloxane in several muscles (*Triceps brachii*, *Vastus lateralis* and *Vastus intermedius*) with livery-off-flavor support the theory that lipid oxidation is a component of this off-flavor.

Livery flavor increases and beef flavor decreases in some muscles as iron content increases (Calkins and Cuppett, 2006b). Muscles often exhibiting liver-like flavor, such as the *Psoas major* and *Gluteus medius* have higher levels of heme iron and/or myoglobin (Yancey et al., 2006).

Beef from bulls has a stronger liver-like odor/flavor and bloody flavor that appears to be related to higher 2-propanone and ethanal contents, while that from heifers has stronger beef flavor (Gorraiz et al., 2002). Carcass maturity can affect iron content and increase off-flavors. Calkins (2006) reported that 30-40% of cow meat samples had metallic and sour notes and 10-20% had rancid, bloody, salty and bitter flavor notes.

Volatile compounds generated by microbial growth on stored, refrigerated meat are major components of off-odors which signal the end of shelf-life. As microbial number increases from 100 thousand to 1 billion cells/g, raw beef develops a "non-fresh" odor and specific volatiles increase (acetoin, diacetyl, 2-methyl propanol and 3-methyl-1-butanol; Dainty et al., 1984). When microbial numbers exceed 1 billion cells/g, ethyl esters of acids with "sweet" or "fruity" odors can be detected. Sulfur-containing compounds may not be detected until microbial numbers exceed 5 billion cells/g, by which time the meat shows obvious visual signs of spoilage and exhibits a sweet, putrid odor.

Summary

Overall, beef flavor results from a myriad of compounds present in varying proportions that are affected by the precursor compounds available (fatty acids, proteins, etc.). This may depend on the breed of cattle and their diet, post-mortem changes (enzyme activity or aging), the muscle in which changes are occurring, addition of ingredients (enhancement, marination), storage conditions (time, temperature, gas atmosphere), heat treatment and post-heating storage. Development of meaty, beefy flavor may be accompanied by development of a variety of off-flavors (livery, rancid) because many of the same precursor compounds are in both flavor groups being differentiated by proportions of the various components and the absolute concentrations of them. Impacting flavor requires control of all these various facets of flavor development.

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*Steak acceptance by consumers is high
when beef flavor, tenderness and juiciness
ratings are high.*

– Platter et al., 2003





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