DEVELOPMENT OF AN INTACT MUSCLE PORK FLAVOR LEXICON

A Thesis

by

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ABSTRACT

A fresh intact muscle pork flavor lexicon was developed by obtaining cuts of pork (pork loins, shoulders, picnics, tenderloins, fresh ham legs, bellies, enhanced picnics and pork chops) from retail grocery stores. Varying cooking temperatures, cooking techniques, and cuts induced differences in flavors and aromas. These cuts were cooked to various internal temperature endpoints (57.2°C, 62.7°C for roasts, 68.3°C, and 79.4°C) utilizing a high temperature cooking method for chops, and roasting and/or braising for whole muscle cuts.

Five highly trained panelists identified and defined twenty-four aroma and flavor attributes. Pork identity, brown/roasted, bloody/serumy, metallic, and fat-like flavor aromatics, and astringent feeling factors, and 4 of the 5 basic tastes were most prevalent in samples. Validation of the pork lexicon was performed. Trained panelists evaluated tenderloin medallions, and loin chops, inside ham chops, and shoulder chops cooked to four internal endpoint temperatures (62.7°C, 68.3°C, 73.8°C, and 79.4°C). Pork identity, brown/roasted, fat-like, bloody/serumy, metallic, liver-like, and nutty flavor aromatics, and astringent feeling factors, and sweet, sour, salty, bitter, and umami basic tastes were present in samples. All attributes but bitter basic taste ($P > 0.05$) differed across cuts ($P < 0.05$). All samples had moderate levels of pork identity flavor aromatics. Umami basic taste and liver-like, nutty, and fat-like flavor aromatics and astringent feeling factors were barely detectable. Shoulder chops were higher in pork identity and fat-like flavor aromatics and umami basic taste. Inside ham chops were

higher in astringent feeling factors and metallic flavor aromatics, and sour and bitter basic tastes. Brown/roasted, bloody/serumy, and metallic flavor aromatics, and astringent feeling factors, and sour and bitter basic tastes differed across internal endpoint temperatures ($P < 0.05$). As internal endpoint temperatures increased, brown/roasted flavor aromatics increased, while bloody/serumy flavor aromatics and astringent feeling factors, and sour and bitter basic tastes decreased.

Gas chromatography with olfactory sniff ports detected volatile aromatic compounds (n=157) found in the samples. Stepwise linear regression equations and simple correlation coefficients were calculated. Stepwise equations used 50, 42, 43, 58, 33, 37, 75, 53, and 42 compounds to account for 93, 91, 83, 94, 77, 87, 96, 88, and 83% of pork identity, brown/roasted, fat-like, bloody/serumy, and metallic flavor aromatics, and astringent feeling factors, and sour, salty, and bitter basic tastes, respectively which determined volatile aroma compounds that may explain variance of trained descriptive attributes. Sulfur-containing compounds, nitrogen-containing compounds, aldehydes, ketones, acids, alkanes, alkenes, furans, pyrazines, and benzenes influenced pork flavor. Aldehydes were quantitatively higher than other compound classes. Aromatic compounds that clustered with treatments and flavor aromatic attributes varied in partial least squares regression biplots, with a large number of treatments and attributes that clustered with aldehydes and alcohols, and treatments that were cooked to higher internal endpoint temperatures clustered with compounds such as pyrazines and thiazoles.

DEDICATION

This work is dedicated to my family, friends, and colleagues who have supported me throughout my career at Texas A&M University and my time as a graduate student. I am so blessed to have such an amazing support team that continues to root for me even in my most challenging journeys.

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CHAPTER I

INTRODUCTION

Pork palatability has been studied by a large number of researchers to ensure that consumers receive the best quality meat at the best price (Ngapo and Gariepy, 2008; Deethardt and Tuma, 1971; Prusa et al., 2011; Wright et al., 2005). Pork palatability has been defined as juiciness, tenderness, and flavor and while adequate terms and scales have been used and developed for pork juiciness and tenderness (AMSA, 1995; AMSA, 2014), pork flavor attributes have not been clearly defined. Flavor is an important part in consumer liking and acceptance of foods. The Beef Flavor Lexicon was developed by Adhikari et al. (2011) and has been used by the beef industry to improve beef flavor. In this lexicon, attributes of beef flavor were defined. Flavor is a complex sensory attribute that is composed of multiple attributes. Civille and Lyon (1996) defined flavor attributes with references for food as many foods have multiple flavors. By developing a whole muscle pork flavor lexicon, a more complete and standardized measure of pork flavor and aroma can be applied across disciplines and utilized to manage pork flavor.

The objectives of this study were to develop an aroma and flavor descriptive attribute lexicon for fresh intact muscle pork and to validate the lexicon using trained panelists by evaluating various cuts of retail pork cooked to various endpoint temperatures to induce flavor and aroma differences. Additionally, the gas chromatograph-mass spectrometer with olfactory sniff ports was utilized to identify volatile aroma compounds present in the same pork samples that were presented to

panelists. The volatile aroma compounds identified were used to identify the compounds that drive pork flavor and aroma as they relate to the pork lexicon attributes.

CHAPTER II

LITERATURE REVIEW

Biological Detection of Flavor

Flavor can be categorized into aromas, tastes, and mouthfeels and takes place in the sense or stimulation portion of the nose and mouth (Spanier et al., 2001). These can be further subcategorized into volatile (odor/aromas) and non-volatile (tastes, mouthfeels) components. These components are combined in the food product to create what is perceived as flavor.

The basic tastes are made of soluble substances that are perceived on the tongue by taste buds that contain taste receptor cells located on the taste papillae or the epiglottis and palate (Voilley and Etievant, 2006). Inorganic salts contribute to the salty basic taste, organic acids contribute to the sour basic taste, hypoxanthine, caffeine, and amino acids contribute to the bitter basic taste, and sugars and some amino acids contribute to the sweet basic taste (Min and Smouse, 1989). For sour and salty basic tastes, ionization of the chemical compounds in solution elicits these basic tastes and both are mainly concentration dependent (Shallenberger, 1996). However, sour basic taste is a function of pH (Shallenberger, 1996). Hydrogen ions act as the molecule that induces the sour basic taste by increasing the hydrogen concentration and thus increasing acidity. Salty basic taste is exclusively dependent on the cation and anion, where sodium chloride is the purest of salty basic taste. Sweet basic taste is more dependent on functional groups and structure, as a specific pair of functional groups, usually dipolar

molecules, results in the sweet basic taste, a proton donating AH auxogluc functional group and a proton accepting B glucophore functional group, that results in intermolecular hydrogen bonding with corresponding AH and B receptors on the tongue. The AH/B theory is further explained for intensely sweet molecules, where a γ site is attracted to the lipophilic regions of the sweet receptor on the tongue, however, it is not as important for sugar sweetness (Birch, 1981). Amino acids that contribute to bitter basic taste are associated with hydrophobic side chains (Min and Smouse, 1989). There are also many other classes of compounds that elicit bitter basic taste (Voilley and Etievant, 2006) such as caffeine, quinine, theobromine, and isohumulone. Additionally, the structure and receptor relationship is similar to that of sweet basic taste. Umami, a newer and less recognized basic taste, is triggered by glutamate and nucleotides that are present in protein-rich foods (Voilley and Etievant, 2006) and also has congruent taste receptors on the tongue. The most common substances used commercially are monosodium glutamate and the 5'-ribonucleotides such as inosine-5'-monophosphate and 5'-IMP (Kawamura and Kare, 1987), however, not all substances in these classes provide enhancing properties or umami basic taste. This class of compounds tends to contribute "meaty" and "brothy" flavors as well as enhance flavors present in the food matrix.

The sense of touch, or tactile sensitivity across the body, varies widely with the fingertips being most sensitive followed by the mouth and its encompassed parts (Guinard and Mazzucchelli, 1996). The feeling factors are perceived in the mouth as nerve ends in and around the mouth as well as in the nasal passages. These sensations

can be described as mouthfeels and can be defined as all tactile properties perceived when a food enters the mouth until the time it is swallowed (Guinard and Mazzucchelli, 1996). For example, astringent feeling factors, which is a tactile sensation that has a trigeminal component (Guinard and Mazzucchelli, 1996), is the basis for the feeling of puckering or drying associated with the binding of compounds such as soluble proteins (Damodaran et al., 2008) to salivary components, thus reducing salivation in the mouth and stimulating receptors.

The olfactory system has the ability to discriminate among many different odors and can identify a large number at a time (Breer, 2008). The sense of smell is located in the olfactory epithelium, where odorant molecules are inhaled and dissolved into the mucus and detected by cilia (Breer, 2008). Cells that are in the posterior area of the nasal cavity recognize these odorant molecules and olfactory neurons send axons to the olfactory bulb to process the signal. The nose and mouth are intertwined when defining where gustation and odor perception are located in the body. At the back of the mouth is an area where molecules are in limbo between the gustation and olfactory process. This is where retronasal odor perception takes place. This process occurs during eating and swallowing, and is described as the volatiles from the mouth that travel to the nose and are detected in the olfactory epithelium (Lim and Johnson, 2011). This phenomenon is the key to the identification of flavor and aroma in the human body.

Specifically, meat flavor is a combination of all of these senses as detected in the body. It is understood to be the result of the various reactions that take place during cooking due to the lack of flavor in raw meat (Shahidi, 1994), however, the basic

biology of the meat and antemortem and postmortem influences impact the end product flavor.

Intrinsic Meat Flavor Components

Flavor precursors relating to meat flavor include water-soluble components and lipids in the meat system (Mottram, 1998). The water-soluble components include sugars of varying types (phosphates, free sugars, and nucleotide sugars) and nitrogenous compounds (peptides, free amino acids, nucleotides, and others). Combinations of specific sugars and nitrogenous compounds have provided meat-like flavors, such as cysteine, a sulfur-containing amino acid, and ribose. Sugars that are present in the muscle come from the hydrolysis of glycogen or the hydrolysis of nucleotides, yielding the two main sugars available, glucose and ribose (Shahidi, 1994). Nitrogenous compounds originate from a variety of components such as free amino acids, proteins, and nucleotides. Each of these components is active in the formation of Maillard reaction products. More on these reactions will be presented in the Maillard reaction section.

Proteins play an important role in the function of muscle as well as being potential flavor precursors. Myofibrillar proteins have been found to provide flavor precursor compounds through the hydrolysis of the protein into sulfur-containing amino acids and non-sulfur-containing amino acids. Myosin contains much higher levels of methionine and cysteine compared to other myofibrillar proteins (Pearson et al., 1983). Other myofibrillar proteins that contain sulfur-containing amino acids are C-protein and G-actin at lower levels. The sulfur-containing amino acid, cysteine, can be broken down

into ammonia, hydrogen sulfide, and acetaldehyde (Damodaran et al., 2008). Acetaldehyde can then combine with other compounds to provide meat flavors. Sulfur compounds, such as hydrogen sulfide, have been shown to be a component in meaty flavors and aromas at low concentrations (Wasserman, 1972). Hydrogen sulfide can react with compounds such as furanones to form 2-methyl-3-furanthiol and bis-(2-methyl-3-furyl) disulfide that present intense meaty flavors (Shahidi, 1994). Sulfur compounds can provide positive or negative flavors, and is very dependent on concentration and quantity. Hydrogen sulfide does not have a large presence in raw pork proteins (Gorbatov and Lyaskovskaya, 1980). Cooked pork contains 1-3 times more hydrogen sulfide when compared to cooked beef due to the higher number of free sulphydryls that are free for heating due to a number of reasons such as thiamine degradation. Other sulfur compounds have been found as well: methyl mercaptan, ethylene sulfide, and thiophene (Gorbatov and Lyaskovskaya, 1980). The sulfur-containing amino acids are most notorious for combining with reducing sugars to produce meat-like flavors in the Maillard reaction (Shahidi, 1994). Myofibrillar proteins also provide amino acids that do not contain sulfur but have been proven to be flavor precursors (Pearson et al., 1983). Myosin provides the majority of these amino acids, with the most important for flavor generation being alanine, leucine, isoleucine, histidine, arginine, proline, glutamic and aspartic acids (Pearson et al., 1983). Some of these amino acids exhibit sweet notes, while others exhibit bitter tastes (Shahidi, 1994). Sarcoplasmic proteins, such as myoglobin and hemoglobin, have not been shown to

contribute to flavor (Hornstein and Crowe, 1960; Pearson et al., 1983). However, myoglobin may have an effect as a prooxidant in lipid oxidation (Pearson et al., 1983).

Protein degradation occurs at about 30°C, where amino acids or nucleotide fragments can be removed from the whole protein (Wasserman, 1972). At temperatures between 35°C and 50°C, muscle fibers begin to lose shape and sulfur groups are exposed. Coagulation of proteins occurs from 55°C to 80°C. Above 80°C, disulfide bonds are formed and beyond 80°C, H_2S molecules are released from the proteins.

Fats, or lipids, are stored in the adipose tissue or as intramuscular fat (marbling). A lipid consists of a head portion, which consists of a glycerol molecule, and a tail portion with three distinct fatty acids linked to the glycerol molecule by ester bonds yielding a triacylglycerol or triglyceride. Fatty acids vary in their functional properties and functions due to their varying lengths and the presence of double bonds (unsaturated fatty acids) versus the absence of double bonds (saturated fatty acids) within the hydrocarbon chain. The triglyceride, also known as a neutral lipid, makes up the majority of adipose tissue (Wood et al., 2008). Phospholipids are in a class of lipids that are present in most plant and animal membranes of aqueous cells (Min and Smouse, 1989). In meat, they are mainly present in the lean muscle in the cellular membranes (Wood et al., 2008). They are composed of a phosphate group and two long chain fatty acids attached to it. The polyunsaturated fatty acid (PUFA) reaction with the phospholipid amine base has the ability react and combine with reactive carbonyls to produce carbonyl-based off-flavors (Min and Smouse, 1989).

Adipose tissue, also known generally as "fat", composition is comprised of amino acids, proteins, sugars, and salts (Wasserman, 1972). Wasserman and Spinelli (1972) determined that adipose tissue was the result of species-specific fat flavor, and the adipose tissue contained both nonpolar and polar lipids. Washing of the adipose tissue resulted in the loss of amino acids. They determined through a trained panel that adipose tissue extract of beef aromas was not easily distinguishable but were described as generally "meat-like" aromas, but lamb and pork extracts were distinguishable with words such as "piggy", "sour", and "goaty". Gas chromatography studies showed that the differences between washed and unwashed lipid composition was mostly quantitative. Washed lipids on heating had hot fat aromas and unwashed lipids had meat-like odors and the water washes contained "basic roast meat aromas". Species-specific differences in flavor are generally recognized to be not in the lean muscle but in the fat on the animal (Hornstein and Crowe, 1960; Mottram, 1998). This was first demonstrated in raw beef, and later in pork, by determining that flavors present in meat could be extracted using water, and then analyzing the fat for fatty acids and carbonyls as potential flavors (Hornstein and Crowe, 1960). The researchers found through analysis of the fat from both species that there were differences in fatty acids present (Hornstein and Crowe, 1960). The biggest difference in fatty acid composition was the high level of linoleic (18:2) and linolenic (18:3) acids in pork compared to beef. Pork fat and beef fat had many of the same fatty acids present but at different concentrations, where beef had higher palmitic acid and hexadecenoic acid. Results for carbonyls present in both samples of fat determined that pork fat had many more carbonyl

compounds such as 2,4-dienals, 2-enals, and alkanals, than beef fat and at different concentrations.

Intramuscular fat (IMF) has been studied with its effects on flavor as well as other attributes (tenderness, juiciness). IMF, also known as marbling, is deposited in the muscle within the perimysium (Nishimura, 2010). The National Pork Board has determined a target range of 2-4% IMF in pork (Meisinger, 2002) for pork quality. While this is a range that fits most studies that have been conducted, there are other studies that have not found any profound effect of IMF on flavor . The variability in these results is rather complex in that many other factors must be controlled to ensure that these studies are accurate (i.e. endpoint temperature, breed, aging, etc.; Ngapo and Gariepy, 2008).

Lipid oxidation is a major concern, where undesirable flavors such as painty, fishy, and rancid could potentially be present in the lean meat. However, autoxidation is a source of volatile compounds in pork (Shahidi, 1994). When oxidation occurs while cooking, the degradation reaction is quick, causing triglycerides and phospholipids to degrade via several different possible hydrolysis reactions, providing an array of desirable flavors (Mottram, 1998; Shahidi, 1994). Lipids in the meat contribute to many flavor-related volatile compounds. Several of these volatiles include hydrocarbons, ketones, alcohols, carboxylic acids, esters, and aldehydes (Mottram, 1998). Volatile compounds such as those listed are indicative of pork cooked at or below 100°C (Shahidi, 1994). Fats also have the ability to carry fat-soluble substances that can be detected by the nose (Shahidi, 1994). Cooked meat and meat that has been reduced in

particle size or has been cooked causing protein denaturation is more readily available for lipid oxidation when compared to raw meat (Min and Smouse, 1989) due to the release of compounds that catalyze lipid oxidation such as free iron from color pigment compounds (Drumm and Spanier, 1991). Fatty acid oxidation is comprised of three steps that are a result of free radical reactions or the result of lipoxygenase (Ho and Chen, 1994). Initiation is the result of the formation of an alkyl radical from the removal of a hydrogen ion from the fatty acid (Ho and Chen, 1994) and is stabilized by the shifting of double bonds on a weaker unsaturated fatty acid. Heat, light, and metals further catalyze the initiation step. Propagation occurs when atmospheric oxygen is bonded to the alkyl radical. The result is a high-energy peroxyl radical that is available to remove hydrogen from a different fatty acid molecule. The result of this is a hydroperoxide molecule as well as the development of a new alkyl radical from another fatty acid molecule. Termination is the result of two free radicals that combine into a non-reactive compound. The unstable hydroperoxides eventually yield volatiles and off-flavors such as aldehydes, ketones, furans, alcohols, and hydrocarbons that are unpleasant (Drumm and Spanier, 1991). Lipid oxidation is difficult to prevent once the free radical chain reaction has occurred, especially when raw meat has been subject to lipid oxidation. This would cause the lipid oxidation to be greater in the cooked meat (Min and Smouse, 1989).

Fatty acid composition was measured by Enser et al. (1996) in pork, beef, and lamb from retail supermarkets in the United Kingdom. The results indicated that the fatty acid composition was similar when comparing intramuscular fat and adipose tissue,

as adipose tissue had more total fatty acids. Total fatty acid composition of the *longissimus dorsi* was highest in lamb, and lowest in pork. Pork had significant levels of long chain (C20-C22) n-3 PUFA in subcutaneous fat as well as the PUFA linoleic acid (18:2*n*–6), a dietary fatty acid that can be deposited upon digestion into the tissues (Wood et al., 2008) in both locations. Phospholipids containing 18:2 were greater in pigs in the *longissimus dorsi* muscle. Red muscle types have been shown to have higher phospholipid levels and thus higher levels of PUFAs than white fiber types (Wood et al., 2003). The results indicate that pork would most likely, overall, be more susceptible to lipid oxidation and thus possibly more susceptible to off-flavors from lipid oxidation in the meat.

Myoglobin is a globular protein with a heme ring that binds oxygen in the muscle and the level of it in the muscle varies across species, sex, physical fitness of the animal, and muscle type (Calkins and Hodgen, 2007). It is responsible for the red color of fresh meat (Winstanley, 1979). Across species, beef tends to have more myoglobin and have a higher hue angle than pork. Across sexes, females and castrates tend to have less myoglobin in their muscles when compared to intact males. The myoglobin differences across muscles are due to the frequency of each muscle fiber type in each muscle (red versus white fiber type present); (Winstanley, 1979). Myoglobin can react with several different compounds to induce color changes in the meat; however, its ability to partake in different reactions is dependent on its chemical state.

Extrinsic Meat Flavor Components

Pork quality differed across breeds (Wood et al., 2004), and crossbreeding has become a common practice in the pork industry to engineer animals to meet production and meat characteristic demands. Common commercial breeds in the United States include Berkshire, Chester White, Duroc, Hampshire, Landrace, Poland China, Spotted Pig, and Yorkshire. Wood et al. (2004) performed a study on Duroc, Large White, Berkshire, and Tamworth identifying the effects of breed, diet, and muscle on fat deposition and quality. Their results showed that pork flavor was higher in Duroc and Large white, and abnormal flavor and flavor liking was higher in Berskhire and Tamworth. Researchers from the Danish Meat Research Institute conducted a study on crossbreeding Duroc and Landrace pigs with alternative breeds, Iberian and Mangalitza (Straadt et al., 2013) and studied the overall pork quality with emphasis on fatty acid composition and subcutaneous fat. The results indicated that no significant differences were found between the crossbreeds and traditional breeds in terms of flavor/taste and odor, with the only difference being improved texture. Additionally, Lu et al. (2008) evaluated the flavor and volatile aroma differences between crossbred pigs (Duroc x Landrace x Large White) and indigenous Chinese pigs and evaluated how intramuscular fat and total fatty acid composition, crude protein and amino acid content, volatile aroma compounds, and sensory evaluation affected flavor in these breeds. The crossbred pigs had lower levels of intramuscular fat, higher levels of PUFA phospholipids, higher levels of crude protein and thus higher levels of amino acids, and lower pork flavor intensity and flavor liking. The Rongchang and Laiwu breeds had higher levels of

intramuscular fat and crude protein levels, the Rongchang breed had lower levels of PUFA phospholipids, and the Laiwu and Dauabai breeds had the highest rankings for pork flavor intensity and flavor liking. The Chinese breeds had the highest sulfur-, nitrogen-containing, and alcohol and ketone compounds, which correlated with the increased intensity and liking. The crossbred pigs also had the lowest concentration of Maillard reaction products.

Gender has an impact on pork quality. For example, intact males have a higher lean to fat ratio when compared to castrates and gilts and generally have values that fall in between the intact males and castrates ratios (Newell and Bowland, 1972; Walstra, 1974; Judge et al., 1990) which is beneficial and important to the pork industry for manufacturers to be able to receive more money for each pig. Therefore, it is important to mention gender impact on pork flavor, with particular interest in boar taint. Generally, males that have not been castrated tend to have increased levels of androstenone and skatole compounds in their fat, which provide an unpleasant odor or flavor (Babol and Squires, 1995). A study by Prusa et al. (2011) compared 5α-androstenone and skatole in the fat and lean portions in barrows, gilts, sows, and boars. The results showed that all types exhibited some boar taint with boar samples most prevalent in boar taint perception using both a trained sensory panel and GC-MS. However, although present in the market, the incidence of boar taint is low due to actions taken to reduce its presence during processing (Babol and Squires, 1995). Walstra (1974) quantified aspects of fattening boars, and determined that strong boar odor could not be detected or was perceived less frequently by consumers or expert

panels from the Netherlands. Judge et al. (1990) supported this information by determining that higher lean meat was present in US facilities with low incidence of boar taint odor. However, the pork industry must still be aware of the percent of the population that can easily detect boar taint. Newell and Bowland (1972) found that 56% of boar carcasses that were cooked during their study were perceived to have a sexual odor, where other carcasses did not impart such odor.

Age is generally associated with live weight and sexual maturity of an animal (Ngapo and Gariepy, 2008). According to Sink (1979) meat flavor intensity tends to increase with the age of the animal due to the increase in nitrogenous compounds in the muscle. No flavor differences besides intensity have been thoroughly researched, however, changes in metabolism, fat level, lipid composition, and muscle pH are present in older animals (Sink, 1979).

The diet of a pig consists of these compositional components: grain source, protein source, energy level, and trace or minor components (Melton, 1990). Fatty acids from the diet are digested differently and utilized differently in pigs than they are in other animals, as their fatty acids are utilized in the fat of the animal and deposited directly into the tissue (Ngapo and Gariepy, 2008), and consequently affect the flavor of the pork (Wood et al., 2003; Melton, 1990). A portion of the dietary fat is delivered to the body tissues where fatty acid composition in those tissues is reflective of the diet of the pig (Corino et al., 2002; Larick, et al., 1992; Miller et al., 1990). Two diets with varied fatty acid compositions were fed to castrated males and females to determine its effects on pork quality (Tikk et al., 2007). The study showed that C18:1n-9c in the polar

lipid fraction found in the rapeseed oil influenced sensory attributes in oven roasts. For roasts, panelists found higher amounts of piggy flavor aromatics and sour basic tastes, when compared to the fried chops. The fried chops had higher sweet odor aromatics and metal flavor aromatics. Additionally, in the chops of female pigs, the polar lipid fraction fatty acids such as C18:2n-6c and C20:3n-6 were correlated with higher fried meat flavor aromatics and sweet odor aromatics from rapeseed oil. These data are in line with the industry view that certain fatty acids, and, as seen in this study, unsaturated fatty acids, influence pork flavor. Ngapo and Gariepy (2008) extensively reviewed the effects of protein source and trace components and concluded that changing these elements have not been shown to affect the flavor of pork.

Muscle cut is an important contributor when considering flavor, as there are a wide number of cuts of pork available to the consumer. These cuts can vary in muscle type and number, as well as myoglobin content, lipid composition, and proteins present (Cornet and Bousset, 1999). There are four different muscle fiber types that differentiate between muscles and group of muscles: slow twitch oxidative (Type I), fast-twitch oxidative-glycolytic (Type II), fast-twitch glycolytic (Type IIB) and Type IIX (Brooke and Kaiser, 1970; Lefaucheur et al., 1998) where glycolytic (carbohydrates are used as fuel in the muscle) and oxidative (fatty acids are used as fuel in the muscle) describe muscle groupings (Ngapo and Gariepy, 2008). Glycolytic muscles, such as the *longissimus dorsi*, oxidative muscles, such as *masseter*, and an intermediate muscle, such as *trapezius*, were compared for amino acid precursors to flavor (Cornet and Bousset, 1999). The major amino acids present in each of the three muscles were

alanine and histidine evaluated together, glutamine, glutamic acid, taurine, hydroxyproline, and carnosine. Oxidative and glycolytic muscles presented different amino acids and at different concentrations, which demonstrated that there could be differences between muscles that could result in flavor differences.

Enhancement of pork was developed for extending shelf life and enhancing moisture retention in pork products in the retail case (Sutton et al., 1997). The process consists of pumping loins with salt and sodium phosphates or sodium lactates to improve tenderness, flavor, and overall quality. Specifically, the flavor enhancement from the pumped pork is theorized to be due to phosphate's ability to increase water-holding capacity in the proteins and prevent oxidation (Prestat et al., 2002) as well as increasing salt content. Despite these positive properties, phosphates can induce off-flavors, such as soapy flavors, at high concentrations. However, Prestat et al. (2002) found that off-flavors were lower in pumped loins (sodium tripolyphosphate, salt, water) than the controls. Additionally, they found that pumped loins had an improved pork flavor, and pork flavor also increased, with decreasing evidence of off-flavors, as the endpoint temperature increased in pumped loins. These findings coincide with findings of other researchers (Sutton et al., 1997) as they found that pumped pork loins with sodium lactate and sodium tripolyphosphate had good sensory characteristics and moisture retention. Pork flavor increased with increased sodium lactate, and was masked by 0.4% phosphates in roasts and overall intensity was lower for roasts pumped with phosphates. The use of sodium lactate as a non-meat ingredient was also shown to reduce the decline

of pork flavor over time, and can be used as a flavor enhancer and a basic taste enhancer (Sutton et al., 1997; Brewer et al., 1993; Papadopoulos et al., 1991).

Postmortem pork quality has been a major research area for a variety of reasons with key issues defined as water-holding capacity, ideal color, and desirable texture. There are four types of pork quality that can occur: pale, soft, and exudative (PSE), dark, firm, and dry (DFD), red, soft, and exudative (RSE), and red, firm, and non-exudative (RFN), all of which are segmented by changes in metabolites in the muscle (Aberle et al., 2012). Lactic acid buildup postmortem causes a decline in pH, as normal porcine muscle starts at a pH of appoximately 7.4 and decreases to approximately 5.6 within 6-8 hours and finishes to approximately 5.3 within 24 hours (ultimate pH) yielding red, firm, and non-exudative (RFN) pork muscle (Aberle et al., 2012). Other factors, such as stress, can affect the ultimate pH of a carcass. Stress can cause a more rapid drop in pH due to the rapid use of glycogen in the muscle. This situation can cause the muscle to be pale, soft, and exudative (PSE). The dark, firm, and dry (DFD) condition is a more extreme case, where glycogen reserves are completely used up. Many studies have been done on postmortem pork quality to determine tenderness and flavor attributes (Flores et al., 1999) as statistical significance was not reported for effects on meat flavor (Bennett et al., 1973). Studies have also been done on pH specifically, as researchers have attempted to identify the range where flavor is most acceptable. A range of pH 5.8-6.0 has been determined to be an ideal range for overall pork quality based on a culmination of studies (Ngapo and Gariepy, 2008).

Bryhni et al. (2003) identified that an ultimate pH of 6.0 resulted in desirable meat flavors that consumers enjoyed (sweeter, less acidic, weaker meat flavor aromatics). Other studies have identified that a lower ultimate pH had less pork flavor and increased off-flavors (Huff-Lonergan et al., 2002). However, one study done by Jeremiah et al. (1990) investigated muscle quality and frozen storage as it relates to flavor and texture and developed profiles for each. Their results indicated that: 1) long-period storage at freezing temperatures of at least 193 d initiated less balanced flavor and had a considerable amount of off-flavor chemical aromatic and higher amounts of appropriate porky and sweet aftertastes; 2) sour basic taste and bitter basic taste were noted in PSE meat and sweet basic taste decreased; 3) DFD meat had flavor notes relating to fatty and porky flavor aromatics, and sweet basic taste with increasing off-flavors as DFD conditions worsened. A more recent study done by Moeller et al. (2010) evaluated the effects of ultimate pH, intramuscular fat, color, and Warner-Bratzler shear force on the effects of eating quality of boneless pork loins. Trained panelists evaluated for cooked pork fat flavor aromatics, salt basic taste, cooked pork lean flavor aromatics, as well as other textural properties. Mean sensory scores as affected by pH were less favorable as pH decreased. Mean scores for fat flavor aromatics were higher in loins with pH values higher than 5.8. Lean flavor aromatics decreased slightly as pH increased over a pH range of 5.4 and 6.4.

The aging of meat does not have as much influence on pork meat as it does on beef meat, and most have viewed it as a tenderization method only (Ngapo et al., 2012b). Aging consists of storing the product for a number of days to achieve myofibrillar

protein breakdown. However, the process does influence flavor through the creation of nitrogen-containing compounds such as amino acids and peptides, which may contribute to the Maillard reaction. Ngapo et al. (2012b) compared cooking method, age, and marbling on pork loins for sensory quality. The investigators found the influence of aging on grilled pork, as opposed to roasted pork, to be minimal, influencing attributes (pork flavor/odor, meat flavor, cardboard odor, metal flavor, and vegetable flavor aromatics), with most influence occurring at around 8-12 d of age. Ngapo and Gariepy (2008) discussed that 6-10 d age had a positive effect on overall palatability as well as had greater impact on it when compared to other factors such as breed. The researchers that supported this claim found that pork flavor increased while off-flavor aromatics and sour basic taste decreased at 6-10 d age (Jeremiah and Gibson, 1997).

Effects of cooking conditions on flavor are not as clear for pork as has been shown for tenderness and juiciness. Wood et al. (1995) conducted two experiments, one with loin steaks and one with leg roasts, with the objective aimed at determining the effect of cooking conditions on the eating quality of pork. The grilled loin chops showed that an increase in final internal temperature from 65°C to 80°C influenced pork flavor aromatics with unit values increasing by 0.6 units. This same increase in final internal temperature affected the pork flavor aromatics of roasted leg roasts with unit values increasing by 0.3 units. The researchers recommended an ideal cook temperature for loin steaks to be 72.5°C and 80°C for leg roasts for optimal flavor. The results of these experiments obtained similar data when compared to a study done by Heymann et

al. (1990). Interestingly, Wood et al. (1995) stated that boar taint compounds, such as androstenone and skatole, may be masked at higher temperatures.

A study done by Myers et al. (2009) consisted of preparing ground beef patties and ground pork patties and cooking them to 66°C and 71°C to compare degrees of doneness and its effect on flavor. They found that these temperatures did not impart any differences in flavor. Another study done by Moeller et al. (2010) supported this work, where they measured end point temperatures of 62.8°C, 68.3°C, 73.9°C, and 79.4°C for pork loins and found that there were no appreciable effects on flavor as determined by a trained panel. However, other studies that were done previously did not provide the same data (Berry, 1994; Kregel et al., 1986), as their meat was cooked to higher degrees of doneness (71°C and 77°C). Degree of doneness as it relates to flavor may be influenced by the Maillard reaction (Myers et al., 2009).

Mottram (1985) determined cooked pork volatiles through the use of Tenax gas chromatography as effected by cooked temperature (grilled steaks: light = 10 min/side; medium = 15 min/side; well-done = 30 min/side; roasts: oven set to 180°C and cooked until internal temperature reaches 70°C). His study found that highly cooked pork contained 66 different heterocyclic compounds, predominantly pyrazines and others such as thiazoles, thiophenes, furans, pyrroles, and oxazole, whereas pork cooked to lower degrees of doneness contained fewer heterocyclic compounds, such as pentylfuran and acetylthiazole, and contained more oxidative compounds. Compounds that were found in all samples were alcohols, aldehydes and other heterocyclic compounds. Production of alkylpyrazines and thiazoles, as mostly demonstrated in well-done pork,

were products of the Maillard reactions, whereas acetylthiazole was found in less severe cooking procedures such as boiling or light grilling.

The Maillard reaction occurs on the surface of the meat where free amino acids and the reducing end of a reducing sugar, such as the carbonyl end of a sugar, condense to form a glycosylamine and is favorable in weak basic conditions, with Aw = 0.4-0.8, and relatively high temperatures (Mottram, 1998; Calkins and Hodgen, 2007; Shahidi, 1994). This compound is rearranged and dehydrated to form a variety of intermediate compounds, most notably furfurals and furanones (Mottram, 1998) that can react with components in meat (Calkins and Hodgen, 2007) such as reactive compounds that include amino-containing compounds and sulfur-containing compounds (Mottram, 1998). Intermediates from the Amadori rearrangement can participate in Schiff base pathways or Strecker degradation resulting in even more varieties of compounds. As noted, Strecker degradation is of notable importance for creating compounds that contribute to flavor and aroma. The process involves removing the carboxylic acid group and the amine group from the amino acid to create an aldehyde as a dicarbonyl that is transformed into an amino alcohol (Mottram, 1998). Of importance to meat, sulfur compounds created during Strecker degradation and the Maillard reaction are derived from cysteine and ribose (Mottram, 1998). The basic fundamentals of the Maillard reaction are still best illustrated by Hodge (1953). Carbonyls from lipid reactions have the ability to react with Maillard intermediates to create compounds that contribute to the aroma of pork (Shahidi, 1994).

Measuring Flavor

Descriptive analysis is used in obtaining specific descriptors for aroma, flavor, and texture and quantifying the values for those descriptors. Additionally, descriptive analysis can be used in quality control, shelf-life studies, research and development, and other areas. The qualitative aspect and the quantitative aspect are the two main components of descriptive analysis. The qualitative aspect encompasses all attributes of a product that provide the big picture of what the product is (Civille and Oftedal, 2012). Examples of these characteristics may include flavor characteristics such as olfactory sensations (vanilla, for example), taste sensations such as salty basic taste, and oral feeling factors such as metallic (Civille and Oftedal, 2012). The quantitative aspect is determined by the intensity or degree with which the characteristic or attribute can be identified on a set scale (Civille and Oftedal, 2012). There are several descriptive analysis methods, ranging in complexity and statistical strength as well as expense and length of time required maintaining and using them. They include the Flavor Profile Method, Texture Profile Method, Quantitative Descriptive Analysis™, Free Choice Profiling, Spectrum Descriptive Analysis Method™, and generic descriptive analysis (Murray et al., 2001). Descriptive analysis methods can be used to define the triangular relationship between descriptive sensory, consumer sensory, and instrumental methods (Murray et al., 2001).

Descriptive analysis techniques can be used to develop a lexicon, which is defined as a set of words to describe a product (Drake and Civille, 2002). The lexicon development procedure usually includes selection of panelists, selection of samples,

developing necessary protocols for running a trained panel, ballot development or generation of attributes and definitions, identifying references, and putting the lexicon to practice through examples and training as well as validation (Lawless and Civille, 2013). Panelists are chosen based on their ability to detect minute differences in flavors between products through the use of acuity tests, discrimination tests, ranking tests, and directional tests (Drake and Civille, 2002). There are a number of other requirements that make a potential candidate an integral part of the panel. Some essential questions to ask the panelists are: availability, health of the potential candidate, lack of allergies, and likeness for food in general (Murray et al., 2001). Sample selection is crucial to the success of lexicon development. For a particular food category, it is important to present samples that accurately represent the availability of that product on the market. Factors to consider for any food product would be variety of brands, geographical regions, gender, breed, cut, etc. depending on the type of product. If the product can be prepared in a variety of ways, then presentation of the product prepared in various ways is necessary to ensure that the researchers encompass all aspects of the product.

Creating and maintaining proper protocols throughout the lexicon development process is crucial to ensure that all samples and conditions are maintained the same way. Sample preparation, procurement, presentation, and evaluation procedures should be consistent (Lawless and Civille, 2013). Additionally, ensuring that panelists are trained prior to term development is crucial for the success of the lexicon. Generation of terms and definitions is initiated by presenting approximately 5-10 samples to panelists per session and they will generate a preliminary list, and once all samples have been

evaluated and all terms have been determined, definitions for each attribute will be determined (Lawless and Civille, 2013). These definitions will then be used to determine references to accurately represent each attribute determined by the panel. The lexicon can then be validated using a trained panel to ensure that the terms for the attributes that are outlined in the lexicon are accurate for the product. Lexicons have been developed for a wide variety of products such as cheddar cheese (Drake et al., 2001), soymilks (N'Kouka et al., 2004), soy sauce (Cherdchu et al., 2013), and green tea (Lee and Chambers, 2007). Due to the use of standardized references and attributes for lexicons, it is possible to use lexicons across institutions and obtain similar results. Adhikari et al. (2011) developed the beef lexicon as mentioned previously. The lexicon was further validated by Philip (2011). Three universities with highly trained panelists, all of which received the same beef samples and the references that were part of the lexicon, were utilized during this study. The study showed that, when three different highly trained descriptive analysis panelists utilized the beef lexicon across different cuts of beef, panelists from each location were able to identify and rank the intensities of the attributes outlined in the lexicon.

Lexicon development for fresh meat has recently been of interest in the research community. Maughan and Martini (2012) created a lexicon to generally rank attributes for different types of fresh meat (chicken, pork, beef, lamb, and turkey). Some general attributes used included astringent feeling factors, bloody, brothy, browned, gamey, grassy, and oxidized flavor aromatics, and salty, bitter, and sour basic tastes. They found that beef and lamb closely clustered with similar attributes such as roast beef,

grassy, and livery flavor aromatics, and pork and turkey related to other attributes on the opposite ends of the spectrum such as brothy and juicy flavor aromatics, and sweet and umami basic tastes. Adhikari et al. (2011) worked to develop the beef flavor lexicon that has been a turning point in how beef flavor is evaluated. Several important major notes that were identified were the five basic tastes, beef identity, metallic, liver-like, and green hay-like flavor aromatics. Some minor notes that were identified were: asparagus, cocoa, buttery, dairy, green, and apricot flavor aromatics. Carlucci et al. (1998) performed a sensory study on young goat meat, and developed some flavor and texture definitions. The flavor and aroma attributes that were developed were blood, goat and meaty flavor aromatics.

Several informal fresh pork lexicons have been developed for specific research aims in the area of pork flavor, most with a separate or less prioritized interest in pork flavor. Work outside of the United States has initiated more lexicon development for pork. Meinert et al. (2007a) developed a flavor and odor vocabulary for pan-fried pork. The 6 professional panelists from the Danish Meat Research Institute, who were trained in Quantitative Descriptive Analysis™, were subjected to 4 training sessions that were used to develop a vocabulary using references. These attributes included fried meat, burnt caramel, boiled meat, piggy, cardboardy, metallic, and heart/liver flavor aromatics, and umami, sweet, and sour basic tastes. Meinert et al. (2007b) developed a similar lexicon for the pork *semimembranosus*. Attributes that were different were acidic, roasted nut, and burnt flavor aromatics, and salty basic taste. Meinert et al. (2009) studied the flavor development in the *longissimus dorsi* from different sectors of raw

meat quality and did not have attribute differences when compared to other Danish Meat Research Institute studies.

Two studies done by Ngapo et al. (2012a, 2012b) looked at the impact of 1) chilled pork on sensory quality, and 2) marbling and aging on sensory quality. The first study on chilled pork utilized 10 panelists trained using the Spectrum Method™ and attributes were developed using a modified version of Quantitative Descriptive Analysis™ (Ngapo et al., 2012a). Attributes that were determined were meat (odor and flavor aromatics), pork (odor and flavor aromatics), rancid (flavor aromatics), bread crust (flavor aromatics), the five basic tastes, cardboardy (odor aromatics), linseed oil (odor aromatics), rubber (odor aromatics), sulfur (odor aromatics), vegetable oil (flavor aromatics), fish (flavor aromatics), nut (flavor aromatics), metal (flavor aromatics), caramel (flavor aromatics), pig (flavor aromatics). Ngapo et al. (2012b) developed a vocabulary based upon Byrne et al. (1999a) and Bryhni et al. (2003). Byrne et al. (1999a) developed sensory attributes for warmed-over flavor in pork patties coming from the semimembranosus muscle. The researchers utilized literature for initial ballot development and utilized the trained sensory panel to narrow the terms from 45 terms to 16 terms. These specific terms were anchored with references. Principal component analysis was performed on the data and meat-like flavor aromatics clustered closely together (e.g. boiled meat, pork-like, pork lean flavor aromatics, etc.) and metallic, liver-like and blood-like flavor aromatics, and salt basic tastes, etc., were associated (Byrne et al., 1999a). Works done by Byrne et al. (1999a), Byrne et al. (1999b); and Byrne et al. (2001) were a series of papers aimed at developing a warmed-over flavor vocabulary

with standards and references for pork. The latter study focused on the RN gene in Hampshire pigs. The final term count was 22 attributes divided into odor aromatics such as roasted-like, caramel-like, fresh cooked pork meat-like, bouillon-like, linseed oil/paint-like, egg/sulfur/rubber-like; basic tastes such as sweet, sour, salt, bitter, and umami; and flavor aromatics such as metallic, fresh cooked chicken meat-like, fresh cooked pork meat-like, rancid-like, lactic/fresh sour-like, vegetable oil-like, bread-like; and aftertastes including metallic and lactic/fresh sour like. Bryhni et al. (2003) developed a 17-attribute vocabulary consisting of meat (odor and flavor aromatics), pig (odor and flavor aromatics), metallic (odor and flavor aromatics), sweet (odor aromatics and basic taste), off (odor aromatics), acidic/sour (odor aromatics and basic taste), warmed-over (odor and flavor aromatics), bitter (basic taste), as well as texture and color attributes with corresponding definitions. This study did not present any references for panel use. A study done by Corino et al. (2002) studied the dietary supplementation (rapeseed oil, corn oil, and corn oil) on heavy pigs and its effects on sensory quality and overall meat quality. They utilized the difference from control method in conjunction with a lexicon that included words such as pig and rancid (odor aromatics), sweet and salty (basic tastes) and pork flavor (flavor aromatics) as well as some descriptors for texture. This lexicon included standards from whole muscle. The results of this study indicated that the supplement type did not influence sensory characteristics. Flores et al. (1999) developed a lexicon using the Quantitative Descriptive Analysis method for determining how post-mortem meat quality and nucleotide content affected sensory characteristics. Aromatics as determined by the panel were serum, browned, pork,

rancid, and boar taint flavor aromatics, and strange odor aromatics. Basic tastes added to the lexicon included bitter, sour, salty, and sweet. Feeling factors included astringent feeling factors and mouthfilling (as associated with monosodium glutamate).

Instrumental methods are utilized in flavor research and can easily be used in conjunction with sensory methods. Most instrumental methods used to identify flavor and aroma compounds have four distinct steps: collection of volatiles, usually from the headspace of the food matrix, separation of volatiles, identification of each compound, and quantification of each compound (Chambers IV and Koppel, 2013). Common methods for collection and isolation of volatiles for analysis are extraction via supercritical CO_2 or the use of a solid phase microextraction (SPME) sampler; (Chambers IV and Koppel, 2013; Maarse, 1991; Di Donfrancesco et al., 2012). The collected volatiles can then be inserted into the gas chromatograph-mass spectrometer (GC-MS) or a gas chromatograph-mass spectrometer with olfactory sniff ports (GC-O), where the gas chromatograph can separate the compounds and the mass spectrometer identifies each compound (Chambers IV and Koppel, 2013). This system has been used to identify flavor compounds starting at approximately 1,500 flavor compounds to more than 7,000 compounds (d'Acampora Zellner et al., 2008). The olfactory port component helps to identify the difference between volatiles that are odor-active and volatiles that are non-odor-active by the ability to incorporate human detection of odor-active compounds (d'Acampora Zellner et al., 2008; Chambers IV and Koppel, 2013). The peaks that are presented and quantified using this process do not always correlate with the intensity of an odor. As such, it makes the utilization of the sniff ports much more

reasonable since it can be implemented to determine intensity and threshold not based on peak quantity.

CHAPTER III

MATERIALS AND METHODS

Phase I. Lexicon Development

Pork chops (boneless and bone-in loin chops, shoulder chops, enhanced boneless and bone-in pork chops,), picnic roasts (both enhanced and non-enhanced), shoulders (whole roasts), tenderloins (whole roasts and medallions), bellies, and fresh ham legs were purchased from retail stores in the Bryan/College Station, Texas area to include HEB, Walmart, Village Foods, and Readfield's Meat and Deli. Table 1 outlined all muscle categories and treatments used during lexicon validation. All cuts were refrigerated at approximately 5°C until consumed and used within 1 to 3 d of purchase. These cuts were used to create differences in flavor and were cooked at varying temperatures. Chops and tenderloin medallions were cooked to 57.2°C, 68.3°C, and 79.4°C internal temperature endpoints to create differences in degree of doneness and flavor. Chops and tenderloin medallions were cooked on a Presto Flat Griddle (Model 0702306, National Presto, Inc., Eau Claire, Wisconsin), which was set to 204.4°C, and cuts were turned at the halfway point for endpoint internal temperature. Whole shoulders, whole tenderloins, bellies, and fresh ham legs were cooked to 62.7°C endpoint temperature in a gas conventional oven for roasting and on the stovetop for braising. Picnic shoulders were not braised due to their large size. Braising consisted of the product being seared in 15 grams of vegetable oil in a cast iron Dutch oven over high heat (surface temperature of Dutch oven approximately 173°C) on a gas stove for 2

minutes per side and then cooked in 500 mL of double distilled deionized water on medium heat (surface temperature of Dutch oven approximately 149°C) until product internal endpoint temperature was reached as defined in Adhikari et al. (2011). Roasting was defined as product cooked in an aluminum roasting pan on a rack in an oven preheated to 162.7°C and cooked until the product reached its internal endpoint temperature as defined in Adhikari et al. (2011). Additionally, approximately 18 boneless, non-enhanced pork chops were packaged using different methods (polyvinyl chloride (PVC) overlay, modified atmosphere packaging (MAP), and vacuum-packaging) to include flavors associated with each packaging technique in the lexicon. These packaged pork chops were kept in the refrigerator at approximately 5°C. For the PVC overlay, the product was stored on GenPak foam number 2 supermarket trays (product ID number 1002, GenPak, Glens Falls, NY) and wrapped in PVC in the refrigerator for 0 and 3 d. Both the vacuum-packaged product and the MAP products were packaged (MultiVac Chamber Machine C200, Wolfertschweiden, Germany) in Cryovac vacuum-package bags (Model B4173T, Sealed Air Corporation, Simpsonville, SC). The MAP product was back-flushed with 80% carbon dioxide and 20% oxygen mixture (Airgas Inc., Radnor, PA). The MAP samples were kept in the refrigerator for 0 and 8 d. The vacuum-packaged products were stored in the refrigerator for 0 and 14 d. Flavors and aromas were also induced for warmed-over flavor, spoiled/putrid, and refrigerator stale flavor aromatics using boneless, non-enhanced pork chops and ground pork (20% fat). Warmed-over flavor aromatics were induced by cooking ground pork (20% fat) in a Rival electric skillet (Model CKRVSK11, Sunbeam Products, Inc., Boca

Raton, FL) and storing it in an uncovered glass container in the refrigerator at 5°C for approximately 24 hours. Refrigerated ground pork was microwaved for approximately 1 min at 100% power. Spoiled/putrid flavor aromatics were induced by placing raw ground pork (20% fat) and a raw boneless pork chop at room temperature for 6 d. The boneless pork chop was cooked on the Presto Electric Griddle and cooked to an internal endpoint temperature of 79.4°C. The ground pork was cooked in the Rival™ electric skillet and cooked until browned. Spoiled/putrid flavor aromatics samples were not tasted and were smelled for aroma only. Refrigerator stale flavor aromatics samples were induced by cooking ground pork and storing it as described for warmed-over flavor aromatics samples. Panelists were served this sample at approximately 24°C. During cooking, internal temperatures were monitored using copper-constantan thermocouples (Omega Engineering, Stanford, CT) and inserted into the chop or roast's geometric center.

Five highly trained panelists, trained in the Spectrum Descriptive Analysis Method™ were used. The panel had extensive experience in evaluating meat products, and an array of other food products. Trained panelists evaluated the fresh pork products to determine flavor and aroma attributes found in each product. Each panelist tasted the fresh pork products individually, and then the panelists discussed the flavor attributes found in each sample. Once all panelists came to a consensus about attributes, flavor intensity was discussed on a 16-point scale (0 = none, 15 = extremely intense), and discussion of the specific references that would represent each attribute took place. These references were anchored based on the Spectrum Method™ from which the

panelists were trained. The intensity of the references would be based on a 16-point anchored scale (0=practically none, 15=extremely intense). The panel leader used resources from American Society for Testing and Materials (ASTM, 1996; ASTM, 2011) and Adhikari et al. (2011) for determining attributes, references, and definitions. Panelists participated in 18 d of ballot development to determine attributes for the pork lexicon.

Phase II. Lexicon Validation

Once the fresh pork products evaluated during Phase 1 had defined attributes, references, and flavor and aroma intensities with confirmed flavor and aroma differences, trained panelists were asked to evaluate pork samples using the lexicon. Tenderloins (n = 6), boneless pork loins (n = 6), and bone-in shoulders (n = 6) were purchased from Readfield's Meat and Deli in Bryan, TX. Inside hams (n = 6) were donated by Farmland Foods (Milan, MO). Each subprimal was cut to 2.54 cm thickness, vacuum-packaged in Cryovac vacuum-package bags (Model B4173T, Sealed Air Corporation, Simpsonville, SC), and stored at refrigeration temperature for 14 d. The chops were then transferred to the freezer and stored at approximately -20°C and used within four weeks. Once chops were cut from each subprimal, temperature treatments were randomly assigned by location for each replication.

All chops were thawed 24 h prior to panel evaluation by placing the vacuum-packaged pork samples in the refrigerator at approximately 5°C. All chops were cooked to 62.7°C, 68.3°C, 73.8°C, and 79.4°C internal temperature to induce differences in flavor on a Presto Flat Griddle (Model 0702306, National Presto, Inc., Eau Claire,

Wisconsin) set to 204.4°C. The pork attributes that the panelists measured were quantified using a 16-point anchored scale (0 = none and 15 = extremely intense) based on references in the lexicon. Panelists were placed in individual, breadbox-style booths with red lights to mask color differences between samples. This area was separate from the preparation room. Each panelist received double distilled deionized water, unsalted saltine crackers, and fat-free ricotta cheese for palate cleansing between samples. During cooking, internal temperatures were monitored using copper-constantan thermocouples (Omega Engineering, Stanford, CT) inserted into the chop or roast's geometric center. After cooking, products were either held for no more than 20 min in an Alto-Shaam Halo Heat (Model No. 750-TH-II, Alto-Shaam, Inc., Milwaukee, WI) holding oven at 48.8°C on a Corelle plate covered in aluminum foil or served immediately. Fat and ends were removed from each cut and the remaining portion was cut into approximately 1.27 cm cubes selected for serving to panelists that did not contain visible connective tissue or intramuscular fat. Panelists received three cubes per sample for evaluation in an odorless, plastic, transparent cup (56.7 g Solo soufflé cup, Dart Container Corporation, Mason, MI). Each sample was assigned a random three-digit code to prevent bias and treatments were served in random order. Panelists were given approximately 3 to 4 min rest between each sample to reduce sensory fatigue. Each testing day consisted of 8 samples per day randomized by cut and temperature endpoint. The study consisted of 12 d and 96 samples were evaluated. Between each set of 4 samples, there was a 10-minute break to reduce tastebud fatigue. Before each testing day, panelists were presented with a warm-up sample, where panelists discussed

the sample orally and came to a consensus about each flavor attribute. The warm up sample was an extra pork chop that came from a boneless loin that was used for validation. This sample was cooked to the same internal endpoint temperature each testing day to ensure that panelists were ranking similarly and to reduce day variation.

Samples used to validate the lexicon, a total of 94 out of 96 samples which differed in flavor attributes, were used for volatile, aromatic compounds analysis using GC-O technology with Aroma-Trax and sniff port technology (MicroAnalytics-Aromatrax, Round Rock, TX). Samples were obtained during trained panel validation. This ensured samples evaluated for volatile components were similar to samples evaluated by trained descriptive analysis. Approximately 75g of each sample was wrapped in aluminum foil and placed in liquid nitrogen and frozen to -80°C. Samples were stored at -80°C until evaluation for up to 2 weeks. Samples were partially thawed in a waterbath at 60°C and put into glass jars (472mL) with a Teflon septum under a metal screw-top lid heated to 60°C. The headspace was sampled with a Solid-Phase Micro-Extraction (SPME) Portable Field Sampler (Supelco 504831, 75 μm Carboxen/polydimethylsiloxane, Sigma-Aldrich, MO) for 2 h after the sample reached equilibrated to 60°C. Alkane standards (C7 to C30; Catalog #49451-U; Sigma Aldrich, St. Louis, MO, 63103) were run to verify the retention times of sample alkanes and were run prior to and after the experimental samples were run to verify, with retention times, the compounds evaluated by the MS. The SPME was injected into the injection port of the gas chromatograph (GC) (Agilent Technologies 7820A GC System, Santa Clara, CA) where the volatiles were desorbed at 280°C. The sample was processed by the first

gas chromatograph (GC) column (30m X 0.53mm ID/ BPX5 (5% Phenyl Polysilphenylene-siloxane) X 0.5 μm, SGE Analytical Sciences, Austin, TX) and separated compounds based on the boiling point. Through the first column, the temperature started at 40 °C and increased at a rate of 7°/minute until reaching 260 °C. The first column had a program that was designed to leave the heart-cut and cryo-trap open to move compounds to the second column {(30m X 0.53mm ID)(BP20-Polyethylene Glycol) X 0.50 μm, SGE Analytical Sciences, Austin, TX}, which separated compounds by polarity. The GC column then partitioned the sample volatiles into three different columns. One column went to the mass spectrometer (MS) (Agilent Technologies 5975 Series MSD, Santa Clara, CA) to determine compounds and the other columns went to two humidified sniff ports heated to 115°C. Two panelists sat at each glass sniff port to determine aromas events as the compounds were separated. Aroma events were defined when trained panelists identified an odor at the sniff port as compounds were eluted off the GC column. Specific attributes and intensities associated with aroma events were not determined. From this AromaTrax information, aroma-active compounds were determined. The sniff ports, as well as the software for determining aromas, were part of the AromaTrax program (MicroAnalytics-AromaTrax, Round Rock, TX). The panelists that participated in the sniff port portion were part of the development training and testing for the intact muscle fresh pork flavor lexicon.

Statistical Analyses

Data were analyzed using SAS (v9.3, SAS Institute, Cary, NC) using an $\alpha < 0.05$. Means and simple correlation coefficients were calculated using PROC MEANS

and PROC CORR. Stepwise regression was conducted using PROC REG. Independent variables were significant at $P < 0.15$. For Phase II, main effects were defined as cut and internal temperature endpoints and their interaction. Analysis of variance was conducted using PROC GLM. The first analysis tested the effect of panelists and panelists by treatment interactions to assure that panelists evaluated cuts and internal temperature effects similarly. As differences were not reported, sensory data were averaged across panelists within an experimental unit. Data were analyzed with sensory day as a block, with cut, internal cook temperature endpoint, and cut by internal cook temperature endpoint interaction as main effects. When main effects were significant ($P < 0.05$), least squares means were calculated and differences between least squares means were determined using the pdiff function of SAS by performing T-tests. Partial least squares regression was conducted using XLSTAT (2009, Addinsoft, Accresco Software, Inc., New York, NY) where the flavor attributes of pork identity, brown/roasted, fat-like, bloody/serumy, metallic, cardboardy, and liver-like flavor aromatics, and astringent feeling factors, and sweet, sour, salty, bitter and umami basic tastes were defined as dependent variables and volatile aromatic compounds were used as independent variables. Data were presented in a bi-plot with treatments defined to understand relationships between major flavor attributes from the Pork Flavor Lexicon attributes, volatile aromatic compounds, and treatments.

CHAPTER IV

RESULTS AND DISCUSSION

Lexicon Attributes

Twenty-four flavor and aroma attributes including the 5 basic tastes were determined to be components of the pork flavor lexicon (Table 2). Pork identity, brown/roasted, fat-like, bloody/serumy, and metallic flavor aromatics, and astringent feeling factors, and sweet, sour, salty, and bitter basic tastes were major notes found in most samples. It was expected that attributes such as bloody/serumy, metallic, and fat-like flavor aromatics, and salty and sweet basic tastes were present in pork cuts since these were shown to be present in raw pork (Gorbatov and Lyaskovskaya, 1980; Imafidon et al., 1994). The basic tastes have also been shown to be taste attributes in cooked pork in a number of studies (Flores et al., 1999; Ngapo et al., 2012a; Ngapo et al., 2012b).

Other attributes were found in some samples but not as frequently. Interestingly, all panelists found vinegary flavor aromatics in the roasted enhanced picnic and the boneless loin roast. Shahidi et al. (2013) found acetic acid to be present in pork. However, that study did not relate chemical aromatic compounds to lexicons or published aromas. Lexicon studies on pork, as found during this research, have not previously found any flavor or aroma terms related to vinegary flavor aromatic. When panelists in the present study discussed vinegary flavor aromatics, it was defined as separate from citric acid that is usually associated with sour basic taste. Flavor aromatic

attributes associated with oxidation, such as cardboard (Maughan and Martini, 2012; Rhee et al., 2005; Johnson and Civille, 1986), heated oil, warmed-over flavor (Byrne et al., 2001), refrigerator stale, and floral (Calkins and Hodgen, 2007) flavor aromatics were expected as some lipid oxidation was induced to create flavor differences for panelists to evaluate and determine appropriate levels. However, oxidation can occur upon cooking, yielding some flavors derived from lipid oxidation (Mottram, 1998). Thus, some of these flavors were present in non-induced lipid oxidation samples.

Warmed-over flavor aromatics are generally associated with oxidation products that are formed from polyunsaturated fatty acids (Byrne et al., 2001). Warmed-over flavor aromatics that may be associated with lipid oxidation were induced by cooking, refrigerating overnight, and reheating for panelists to evaluate for the lexicon; however, panelists found warmed-over flavor aromatics to be present in a few samples that were not induced with prior preparation. According to Byrne et al. (2001), warmed-over flavor aromatics were determined to be complex with many facets. The original work on warmed-over flavor done by Johnson and Civille (1986) reported similar attributes. The researchers used ground patties of pork, turkey, chicken, and beef and whole roasts of beef. These attributes included cardboard, cooked beef lean, cooked beef fat, and serum/bloody flavor aromatics, and 4 of the 5 basic tastes. Byrne et al. (2001) determined that a warmed-over flavor vocabulary included 15 flavor, aroma, taste, and aftertaste attributes. This vocabulary consisted of similar terms to the present lexicon, including the 5 basic tastes, metallic, nut-like, vegetable oil-like, rancid, and cardboard-like flavor aromatics, and astringent feeling factors. The similarities in these findings

may indicate that descriptors for overall pork flavor aromatics may be present in all pork samples regardless of preparation such as inducing warmed-over flavor aromatics. Additionally, some attributes that contribute to overall pork flavor aromatics may carry over to warmed-over flavor aromatics attributes and vice versa.

The soapy flavor aromatic was an attribute determined by the panelists to be due to the enhancement of some of the intact muscle pork products. Studies done by Prestat et al. (2002) and Sutton et al. (1997) included a soapy flavor aromatics descriptor in the terminology used for trained panelists when evaluating pumped pork loins, indicating that soapy flavor aromatics may play a role in the evaluation of enhanced pork products.

Burnt flavor aromatics were determined by panelists to be in braised products such as pork bellies and pork chops cooked to higher degrees of doneness on the Presto flat griddle. The braised samples had full surface contact with the Dutch oven on the stove for 2 minutes on each side, which may explain the detection of this attribute by panelists. Additionally, loin chops cooked to a higher degree of doneness had exposure to the surface of the griddle for a longer time than chops cooked to a lower degree of doneness, which may have influenced the amount of burnt flavor aromatics present on the surface of the pork chops.

Many attributes were similarly found in the beef flavor lexicon developed by Adhikari et al. (2011). These included: the five basic tastes, bloody/serumy, brown/roasted, burnt, chemical, fat-like, liver-like, warmed-over, refrigerator stale, soapy, heated oil, and floral flavor aromatics. It was not surprising to find similarities between the two lexicons since many of the same terms may be attributed to innate basic

tastes, storage conditions, and attributes that are representative in raw animal meat. The differences in other attributes could be attributed to the difference in species, as well as differences in cook methods and endpoint temperatures. Adhikari et al. (2011) used 3 basic cook methods for all samples and 5 different endpoint temperatures. Additionally, a wider range of categories was used. The pork lexicon study did not include quality grade differences, aging differences, or animal maturity differences.

Astringent feeling factors were found in several studies that used or developed lexicons for pork (Flores et al., 1999; Maughan and Martini, 2012; Jeremiah et al., 1990). It was interesting to see that some studies, such as Byrne et al. (1999a) and Jeremiah et al. (1990), described astringent feeling factors as aftertastes and Flores et al. (1999) specifically determined astringent feeling factors as feeling factors. Astringent feeling factors were found by all panelists to be present in most pork samples presented during lexicon development.

Panelists did not find any off-flavors or oxidative flavors when evaluating products packaged in different packaging systems. When considering pork products that were packaged using modified atmosphere, the mixture that was used was 80% carbon dioxide and 20% oxygen. Because modifying the atmosphere for meat products can have both positive and negative consequences (color stability and organoleptic quality via microbial growth, respectively), it was imperative to include this packaging technique for lexicon development. High oxygen ratios tend to catalyze lipid oxidation, yielding off-flavors derived from this reaction, and carbon dioxide has been shown to inhibit microbial growth (Zhao et al., 1993). Because the ratio of oxygen to carbon

dioxide was not high, it may explain why panelists did not detect oxidative flavors or aromas. Panelists only found pork identity, brown/roasted, fat-like, bloody/serumy, and metallic flavor aromatics and astringent feeling factors, and sweet, sour, salty, and bitter basic tastes.

Adhikari et al. (2011) found other attributes in beef that were indicative of oxidative rancidity, which included liver-like, rancid, warmed-over, and spoiled flavor aromatics. However, in the present study, long frozen pork chops were shown to have cardboardy flavor aromatics as determined by the trained panelists. Cardboardy flavor aromatics have been shown in a number of studies to be present in oxidative samples (Johnson and Civille, 1986; Rhee et al., 2005; Byrne et al., 2001). Floral, chemical, and heated oil flavor aromatics were present in some samples. These minor attributes may be off-flavors that could be expected since long frozen pork chops were frozen for over 2 years. It was interesting to see that the panelists found only cardboardy flavor aromatics to be a result of lipid oxidation, when compared to rancid flavor aromatics. Other studies have determined rancid flavor aromatics to be a flavor attribute to describe meat flavor aromatics (Byrne et al., 1999a; Ngapo et al., 2012a). Heated oil flavor aromatics were also shown to be present in pork bellies that were braised and roasted. Upon visual inspection, most fat on the pork bellies that melted in the pan or dutch oven was cooked until the product reached its internal endpoint temperature and could explain the heated oil flavor aromatics attribute. Other studies may have used similar terms to describe heated oil flavor aromatics, including vegetable oil-like flavor aromatics (Byrne et al., 2001) and vegetable oil flavor aromatics (Ngapo et al., 2012a, Ngapo et al., 2012b).

Several studies were found to have similarities in lexicon terms when compared to the present study. Meinert et al. (2007a) used cuts from the *semimembranosus* cooked to 70°C and pan heat temperatures of 150°C and 250°C. The internal endpoint temperature was approximately 1.7°C different from the middle temperature used in the lexicon development for pork chops. The surface temperature of the griddle in the current study used was approximately 204.4°C that was roughly the median for the pan temperatures used in Meinert et al. (2007a). Thus, there were similarities in some attributes such as sweet basic tastes, and acidic, roasted nut, fried meat, and piggy flavor aromatics. Additionally, Ngapo et al. (2012a, 2012b) outlined attributes for all five basic tastes and pork odor and flavor aromatics that coincide with the basic tastes and pork identity flavor aromatics outlined in the pork lexicon (Table 2). The pork loin chops that were used by Ngapo et al. (2012a, 2012b) were cooked to 72°C on a panini grill that reached 160°C. Pork loin roasts were also roasted to a final core temperature of 72°C. Caramel, bread crust, and sulfur flavor aromatics were attributes associated with increased internal endpoint temperature. Caramel and bread crust flavor aromatics may be similar to the term brown/roasted flavor aromatics defined in this lexicon as bread crust typically has a browned surface from the Maillard reaction since the Maillard reaction tends to occur on the surface of the meat or other food product.

The all-meats lexicon developed by Maughan and Martini (2012) included similar terms to this pork lexicon including astringent feeling factors, and bloody, browned, grassy, fatty, livery, metallic and brothy flavor aromatics, and the five basic tastes. Across all studies, it can be concluded that the basic tastes, meat/pig/pork flavor

and aroma attributes as determined by trained panelists are important for pork flavor. However, the pork studies with terms were developed or used only for each researcher's individual purposes and not necessarily to be used across studies. Additionally, these lexicons provided only qualitative references, and instructions for preparation of references may or may not have been present. Furthermore, these studies did not provide any magnitude or scaling for each reference. The references with defined levels in the present lexicon are a major key to applying the lexicon across studies.

Lexicon Validation

Flavor aromatic attributes and basic tastes were affected ($P < 0.05$) by cut (Table 3). The interaction between cut and internal endpoint temperature was evaluated but was not reported ($P > 0.05$). Pork identity, brown/roasted, fat-like, bloody/serumy, liver-like, metallic, and nutty flavor aromatics, and astringent feeling factors, and sweet, sour, salty, and umami basic tastes differed across cuts ($P < 0.05$); (Table 3). Bitter basic taste did not differ across cuts ($P > 0.05$). Heated oil, cardboardy, soapy, chemical, burnt, floral, warmed-over, refrigerator stale, vinegary, boar taint, spoiled/putrid, medicinal, grassy, bell pepper, dirt, and musty flavor aromatics were not detected. Pork samples had moderate levels of pork identity flavor aromatics. Attributes that were barely detectable in samples were umami basic taste, and liver-like, nutty, and fat-like flavor aromatics. Shoulder roasts cut into pork chops were ranked slightly higher in pork identity and fat-like flavor aromatics and lower in umami basic taste ($P < 0.05$). During cooking, shoulder chops had more visible fat when compared to the other cuts. Bloody/serumy flavor aromatics were slightly higher ($P < 0.05$) in shoulder chops and

inside ham chops when compared to tenderloin medallions and loin chops. Loin chops and shoulder chops were slightly higher ($P < 0.05$) in brown/roasted flavor aromatics when compared to tenderloin medallions and inside ham chops. Loin chops and inside ham chops were slightly higher ($P < 0.05$) in sour basic taste when compared to shoulder chops and tenderloin medallions. Inside ham chops were slightly higher ($P < 0.05$) in metallic flavor aromatics and astringent feeling factors, and sour basic taste than tenderloin medallions and loin chops. This was expected since other studies have indicated similar results. For example, *semimembranosus* muscles cooked in a pan heated to 150°C had higher metallic flavor aromatics and sour basic taste when compared to those muscles cooked in a pan heated to 250°C (Meinert et al., 2007a). Nutty flavor aromatics were not found during lexicon development but were found during lexicon validation; thus, it was included as part of the lexicon. Interestingly, Meinert et al. (2007b) determined roasted nut flavor aromatics to be an attribute in pork and roasted nut flavor aromatics were higher in grilled pork when compared to pan-fried pork chops cooked to the same internal endpoint temperature. However, intensities of the attribute as determined by trained panelists were low, which coincided with the data from this study.

Internal endpoint temperatures (62.7°C, 68.3°C, 73.8°C, and 79.4°C) used for lexicon validation created differences in attributes (Table 3). Brown/roasted, bloody/serumy, and metallic flavor aromatics, and astringent feeling factors, and sour and bitter basic tastes differed across internal endpoint temperatures ($P < 0.05$). Pork identity, fat-like, liver-like, and nutty flavor aromatics, and sweet, salty, and umami

basic tastes did not differ ($P > 0.05$). As internal endpoint temperatures increased, brown/roasted flavor aromatics increased, while bloody/serumy flavor aromatics and astringent feeling factors, and sour and bitter basic tastes decreased ($P < 0.05$). The increase in brown/roasted flavor aromatics was expected as chops that were cooked to a higher degree of doneness were exposed to heat for a longer time. Burnt caramel and fried meat flavor aromatics from Meinert et al. (2007a) may represent or be a component of the attribute brown/roasted flavor aromatics as these attributes increased when pan temperature was increased from 150°C to 250°C. This study also showed that sour basic taste and metallic flavor aromatics decreased with increased pan temperature. Furthermore, a decrease in bloody/serumy flavor aromatics and astringent feeling factors, and sour basic taste was expected as Miller et al. (2014) showed that increasing the degree of doneness of beef resulted in the same trends indicated in this study.

The pork flavor lexicon was successfully developed to find differences in pork cuts that were treated with different methods to induce differences in pork flavor and aroma. All pork cuts had flavor or aroma attributes that seem to be fundamental to pork flavor including pork identity, brown/roasted, bloody/serumy, fat-like, and metallic flavor aromatics, and astringent feeling factors, and the 5 basic tastes. Additionally, the validation of the lexicon showed that cut and internal temperature endpoints that were chosen to create differences in flavor and aroma differed.

Volatile Aromatic Compounds

One hundred and fifty-seven aromatic compounds were defined by the GC/MS and presented in Table 4. These aroma compounds were components of aroma events. Aroma events were defined when trained panelists identified an odor at the sniff port as compounds were eluted off the GC column. Table 4 also included the mean total ion area counts under the curve and the standard deviation for each compound. Some key classes of compounds found were sulfur-containing compounds, nitrogen-containing compounds, aldehydes, alcohols, ketones, acids, alkanes, alkenes, furans, pyrazines, and benzenes (Table 5). Shahidi (1994) reported that common chemical compound categories that have been identified to describe pork flavor aromatics were alcohols, carbonyls, carboxylic acids, sulfur-containing compounds, esters, ethers, lactones, and some heterocyclic compound categories including pyridines, oxazoles, thiazoles, thiophenes, and pyrazines. Mottram (1985) found a total of 66 compounds, which consisted mostly of pyrazines, pyridines, thiazoles, thiopenes, furans, pyrroles, and oxazoles in roasted pork legs cooked to 70°C and grilled chops cooked for 10 min per side for grilled light, 15 min per side for grilled medium, and 30 min per side for grilled well-done. The present study included pork cuts cooked to different internal endpoint temperatures that would expectantly explain the differences in quantities and types of compounds. In the present study, lipid-derived volatiles such as aldehydes, hydrocarbons, ketones, and alcohols were present in treatments as all treatments were cooked below 100°C (Shahidi, 1994). Shahidi (1994) suggested that below this temperature, lipid-derived volatiles were the major components in pork flavor.

Additionally, Elmore et al. (2000) determined 96 volatile compounds to be present in cooked pork. These included Alkanes, aldehydes, alcohols, ketones, furans, nitrogen-containing compounds, sulfur-containing compounds, and acids.

Flavor aromatic compound categories were affected by cut (Table 5). Sulfur-containing compounds, nitrogen-containing compounds, aldehydes, alcohols, ketones, pyrazines, and benzenes differed across cuts ($P < 0.05$). Acids, alkanes, alkenes, and furans did not differ across cuts ($P > 0.05$). Sulfur-containing compounds were present in all cuts except for inside ham chops. Research has shown that sulfur-containing compounds have a large impact on overall "meaty" flavor (Shahidi, 1994). When compared to other species, beef was reported to have the most overall compounds as well as sulfur compounds, whereas pork was reported to have a third of the amount of sulfur compounds when compared to beef (Shahidi, 1994). Nitrogen-containing compounds were highest ($P < 0.05$) in loin chops and inside ham chops when compared to shoulder chops and tenderloin medallions. Nitrogen-containing compounds could have originated from peptides, free amino acids, proteins, thiazoles, pyrroles, or others. Some nitrogen-containing compounds have the ability to react in the Maillard reaction to form new compounds. It was not surprising to see that pyrazines, also a class nitrogen-containing compounds, were lower in pork cuts. Additionally, some nitrogen-containing compounds provide umami basic tastes (Shahidi, 1994). A large number of heterocyclic compounds, such as benzenes, have been shown to be derived from the Maillard reaction (Shahidi, 1994). A wide variety of compounds fall under the benzene umbrella to include pyrazine compounds. Benzenes and pyrazines were present at lower levels in

shoulder chops. Aldehyde levels were the highest value for chemical categories. Similarly, Shahidi (1994) stated that aldehydes represent a large portion of compounds present in pork.

Aldehydes and acids differed across internal endpoint temperatures ($P < 0.05$) (Table 5). Sulfur-containing compounds, nitrogen-containing compounds, alcohols, ketones, alkanes, alkenes, furans, pyrazines, and benzenes did not differ across internal endpoint temperatures ($P > 0.05$). Alkenes were present at higher levels ($P > 0.05$) in chops cooked to 62.7°C when compared to other internal endpoint temperatures. Benzenes, ketones, and nitrogen-containing compounds had similar levels ($P > 0.05$) across all degrees of doneness. The lowest internal endpoint temperature had the highest levels ($P < 0.05$) of acids. "Sour" flavors or basic tastes have been shown to be present in raw pork or pork cooked to lower degrees of doneness since organic acids have been shown to elicit sour basic taste (Shahidi, 1994). Chops cooked to 79.4°C had the highest levels of pyrazines since pyrazines tend to be present in meat cooked to higher degrees of doneness. Meinert et al. (2007a) showed that the *semimembranosus* muscle cooked in a pan that was heated to either 150°C or 250°C temperature and cooked to an internal temperature of 70°C resulted in increased levels of aldehydes and ketones. The present study did not find this relationship, however, surface temperature of the grill was approximately the same when cooking all chops. Aldehydes were present at higher levels in cuts cooked to 62.7°C and ketones were present at higher levels in cuts cooked to 73.8°C.

The interaction of pork cut by internal temperature endpoint was reported for compound classifications (Figure 1). Nitrogen-containing compounds, aldehydes, and benzenes differed across treatments and internal temperature endpoint ($P < 0.05$). Sulfur-containing compounds, alcohols, ketones, acids, alkanes, alkenes, furans, and pyrazines did not differ ($P > 0.05$). Quantitatively, aldehydes were more prevalent in all treatments; however, no clear trend was observed for amount of aldehydes present. As internal endpoint temperatures increased, aldehyde levels tended to increase for tenderloin medallions and decrease ($P < 0.05$) for loin chops cooked to 62.7°C, 68.3°C, and 73.8°C. As internal endpoint temperatures increased, benzene levels in loin chops decreased ($P < 0.05$). Benzene levels were lowest ($P < 0.05$) in tenderloin medallions cooked to 62.7°C and were higher ($P < 0.05$) for all other internal endpoint temperatures. Benzene levels in inside ham chops tended to increase ($P < 0.05$) as internal endpoint temperatures increased, with the exception of inside ham chops cooked to 79.4°C. However, as internal endpoint temperatures for 68.3°C, 73.8°C, and 79.4°C increased for shoulder chops, benzene levels increased ($P < 0.05$). Across all treatments, pork cuts were lowest ($P < 0.05$) in nitrogen compounds. For pork loin chops, as internal endpoint temperatures increased, nitrogen compounds tended to decrease ($P < 0.05$). This was not the case for other cuts. Nitrogen levels tended to increase slightly ($P < 0.05$) for inside ham chops across all internal endpoint temperatures. These trends showed that cuts cooked to the same internal endpoint temperature had differences in compound category levels and trends that occurred as internal endpoint temperature increased, indicating that each cut may have varied levels of compounds that may play a role in pork flavor.

Cornet and Bousset (1999) showed that across three different pork muscle fiber types, amino acid content varied in quality and quantity, indicating that flavor differences could be present. This information may correlate to differences across cut and internal endpoint temperature in nitrogen-containing compounds and possibly benzene compounds. These results imply that differences in classes of compounds were not appreciably impacted as internal cook temperature increased for specific pork cuts, however, individual compounds may have been affected.

Simple Correlation Coefficients

In order to better understand the relationship between trained descriptive attributes and aromatic compounds, simple correlation coefficients were reported in Table 6. Pork identity flavor aromatics were moderately related ($P < 0.05$) to 2,4-decadienal, 1-pentanol, 4-dodecene, (E)-, and butanoic acid. Carboxylic acids, such as butanoic acid, have been identified as contributors to pork flavor (Shahidi, 1994). Czerny et al. (2008) stated that butanoic acid has an odor quality of sweaty. The compound 2,4-decadienal, a lipid oxidation product and an aldehyde, has been shown to be associated with deep fat flavor (Calkins and Hodgen, 2007) and/or green, roasted aroma (Xie et al., 2008). 1-pentanol, also a lipid oxidation product and alcohol, has been shown to have a balsamic, fruit flavor or odor (Calkins and Hodgen, 2007). These results indicate that these aromatic compounds and their published aromas may play a role in describing the flavor and aroma of pork identity flavor aromatics.

Fat-like flavor aromatics were moderately correlated ($P < 0.05$) to 2,3-dimethylbenzaldehyde. 2,3-dimethylbenzaldehyde was expected to have an impact on

fat-like flavor aromatics as Calkins and Hodgen (2007) showed that benzaldehyde tends to have a volatile almond oil or bitter, burning aromatic. 2-decen-1-ol was moderately associated ($P < 0.05$) with bloody/serumy flavor aromatics. 2,4-decadienal and tetradecanal were negatively and moderately correlated to metallic flavor aromatics. As the concentration of 2,4-decadienal increased, metallic flavor aromatics decreased and pork identity flavor aromatics increased. Tetradecanal is an aldehyde lipid oxidation product that has been identified in cooked pork (Shahidi, 1994) and has been identified as having a roasted, fried meat aroma (Xie et al., 2008). As tetradecanal and 2,4-decadienal decreased, metallic flavor aromatics increased. As mentioned earlier, 2,4-decadienal was positively related ($P < 0.05$) to pork identity flavor aromatics, which may indicate that as pork identity flavor aromatics increased, metallic flavor aromatics decreased. 1,2-dimethylpyrrolidine was negatively and moderately related ($P < 0.05$) to astringent feeling factors. As 1,2-dimethylpyrrolidine increased, astringent feeling factors decreased. Because pyrrole derivatives are formed from the Maillard reaction and proteins are denaturing as the product is heated, there could be a decrease in proteins available to precipitate that could cause an astringent feeling factors perception.

Decanal, a lipid oxidation product, has been associated with powerful, waxy, citrus peel flavor and aroma (Calkins and Hodgen, 2007) that was negatively and moderately associated ($P < 0.05$) to sweet basic taste. Decanal, 2,4-nonadienal, and nonanal were all negatively and moderately correlated ($P < 0.05$) to umami basic taste. 2,4-nonadienal has been shown to have fatty, green, floral, grassy, and waxy odors (Czerny et al., 2008; Calkins and Hodgen, 2007), and nonanal has been shown to have

citrus-like or soapy aromatics (Czerny et al., 2008). 2,3-dimethylbenzaldehyde and octadecanal were highly related ($P < 0.05$) to umami basic taste. As decanal increased, sweet and umami basic tastes decreased, whereas octadecanal increased as umami basic taste increased. Octadecanal has an oil flavor or aroma (Calkins and Hodgen, 2007) and is a lipid oxidation aldehyde (Shahidi, 1994). These results indicate that aldehydes, such as decanal, may play a role in masking or reducing umami and sweet basic tastes, and that octadecanal may be a factor in determining umami basic taste. The compound 2,3-dimethylbenzaldehyde was also moderately correlated ($P < 0.05$) with fat-like flavor aromatics, indicating that as 2,3-dimethylbenzaldehyde increased, both umami basic taste and fat-like flavor aromatics increased.

Simple correlation coefficients for classes of compounds as they relate to trained descriptive attributes are reported in Table 7. Nitrogen-containing compounds were negatively and weakly correlated ($P < 0.05$) with fat-like flavor aromatics and bloody/serumy flavor aromatics. Pork identity flavor aromatics were negatively correlated ($P < 0.05$) to alcohols and ketones. Pyrazines were negatively and weakly related ($P < 0.05$) to fat-like flavor aromatics and positively related ($P < 0.05$) to bloody/serumy flavor aromatics. It was not expected that, as pyrazines increased, bloody/serumy flavor aromatics increased since pyrazines are usually indicative of increased internal degrees of doneness and high heat treatments. Brown/roasted flavor aromatics were moderately correlated ($P < 0.05$) to nitrogen-containing compounds and pyrazines. This was not surprising, as pyrazines tend to provide browned or roasted flavors from the Maillard reaction. Benzenes were negatively and weakly related ($P <$

0.05) to fat-like flavor aromatics. Sweet basic taste was negatively and weakly associated ($P < 0.05$) with nitrogen-containing compounds, alcohols, and ketones. Sour basic taste was negatively associated ($P < 0.05$) with aldehydes and acids. This was not surprising since some acids have been described as sour basic taste (Shahidi, 1994). Additionally, umami basic taste was negatively correlated to alcohols and ketones.

Stepwise Linear Regression Equations

Stepwise linear regression equations to predict descriptive flavor attributes for pork identity, brown/roasted, fat-like, bloody/serumy, and metallic flavor aromatics, and astringent feeling factors, and sour, salty, and bitter basic tastes were calculated (Tables 8-16, respectively). These equations used 50, 42, 43, 58, 33, 37, 75, 53, and 42 volatile aromatic compounds to account for 93, 91, 83, 94, 77, 87, 96, 88, and 83% of pork identity, brown/roasted, fat-like, bloody/serumy, and metallic flavor aromatics, and astringent basic tastes, and sour, salty, and bitter basic taste descriptive attributes, respectively ($P < 0.05$).

Six compounds, butanoic acid, 2,4-decadienal, ethylidene cycloheptane, N,N'-dimethylcyclobutane-1,1-bis(methylamine), and 1-heptanol, accounted ($P < 0.05$) for 41% of variation in pork identity flavor aromatics when used in a stepwise linear regression equation (Table 8). Step two in the stepwise linear regression for pork identity flavor aromatics was the addition of 2,4-decadienal. 2,4-decadienal was moderately related ($P < 0.05$) to pork identity flavor aromatics ($r = 0.29$). Additionally, butanoic acid entered the stepwise linear regression equation for pork identity flavor aromatics at step 1 and was moderately related ($P < 0.05$) to pork identity flavor

aromatics (r = 0.33). These data indicated that there might be a moderate relationship between pork identity flavor aromatics and butanoic acid and 2,4-decadienal. 1-heptanol, a lipid oxidation alcohol (Shahidi, 1994), has been shown to have flavor and aroma characteristics of woody, oily, green, herb, and winey (Calkins and Hodgen, 2007) and as pork identity flavor aromatics increased, 1-heptanol decreased. The same trend was shown in the simple correlation coefficients for classes of compounds as pork identity flavor aromatics increased, alcohols decreased ($r = -0.22$; $P < 0.05$). Other classes of compounds that were present were benzaldehyde derivatives, alkanes, and aldehydes.

Six aromatic compounds, 2,3-dimethylbenzaldehyde, 4-ethyl-benzaldehyde, 2,4-nonadienal, 2-heptanone, nonanal, and trans-2-undecen-1-ol accounted ($P < 0.05$) for 38% of the variation in fat-like flavor aromatics (Table 9). Interestingly, two of those were benzaldehyde derivatives. These were the only class of compounds to be moderately related to fat-like flavor aromatics ($r = 0.38$; $P < 0.05$). A large number of aldehyde compounds entered the equation as well such as nonanal, undecanal, and hexadecanal, indicating that lipid oxidation products play a major role in fat-like flavor aromatics. The flavor aromatics associated with brown/roasted had a large number of compounds that entered the stepwise linear regression equation (Table 10). 3-ethyl-2,5-dimethyl-pyrazine entered the stepwise equation at step 1, followed by aldehydes and benzaldehydes. This was expected since the Maillard reaction products such as pyrazines, yield flavors that contribute to roasted flavors. Benzaldehydes were also

associated with fat-like flavor aromatics, which may indicate a positive relationship between brown/roasted flavor aromatics and fat-like flavor aromatics.

Pyrazine compounds entered the stepwise equation for bloody/serumy flavor aromatics (trimethyl pyrazine at step 6, 2,3,5-trimethylpyrazine at step 18, 2-ethyl-3,5-dimethyl-pyrazine at step 19, and 2,5-dimethylpyrazine at step 33) and they are usually associated with Maillard browning and increased temperatures ($P < 0.05$; Table 11). However, β values for these compounds indicated that as bloody/serumy flavor aromatics increased, pyrazine compounds decreased ($P < 0.05$; Table 11). The simple correlation coefficients also showed that bloody/serumy flavor aromatics were negatively associated with pyrazine derivatives. Additionally, 2-decen-1-ol entered the stepwise linear regression equation at step 1 as well as other alcohol compounds including 1-heptanol, 1-pentanol, and 1-octen-3-ol. 1-octen-3-ol has been associated with mushroom or smoke flavor aromatics (Bueno et al., 2011). Other classes of compounds included alkanes, aldehydes, and ketones, indicating lipid oxidation played a role in bloody/serumy flavor aromatics.

One single aromatic compound, N,N'-dimethylcyclobutane-1,1-bis(methylamine) accounted ($P < 0.05$) for 17% of the variation in metallic flavor aromatics and was the first compound to enter the stepwise regression equation (Table 12). As metallic flavor aromatics increased, N,N'-dimethylcyclobutane-1,1-bis(methylamine) decreased, which was also shown in the simple correlation coefficients. Other compounds, specifically those identified as lipid oxidation products, namely aldehydes and ketones, entered the stepwise equation for metallic flavor

aromatics such as heptenal (step 4), 2,4-nonadienal (step 7) 2,4-decadienal (step 8), and 2-heptanone (step 10) and 1-phenyl-ethanone (step 17). 2,4 nonadienal, a compound derived from fatty acid autoxidation to hydroperoxides (Calkins and Hodgen, 2007), was negatively and moderately correlated ($P < 0.05$) to both metallic flavor aromatics and umami basic taste. 2,4-nonadienal was shown to be related to fat, wax, and pungent flavors/aromas (Calkins and Hodgen, 2007). Metallic flavor aromatics had other compounds enter the stepwise equation as well, including 3-ethyl-2,5-dimethyl-pyrazine (step 5) and benzothiazole (step 23).

Astringent feeling factors were negatively associated with 1,2-dimethylpyrrolidine ($r = -0.29$; $P < 0.05$) and entered the stepwise equation for astringent feeling factors at step 1, and as astringent feeling factors increased, 1,2-dimethylpyrrolidine decreased (Table 13). This compound is a heterocyclic nitrogen-containing compound. Eight out of 37 compounds that entered the equation were aldehydes that have been shown to be largely present in pork (Shahidi, 1994).

The stepwise linear regression for sour basic taste showed that a variety of compounds could be used to predict sour basic taste (Table 14). A total of 75 compounds were used in the stepwise regression equation for sour basic taste. The compound 1-heptanol entered the stepwise equation for sour basic taste at step 1 and entered the stepwise linear regression equation at step 2 for astringent feeling factors. Maughan and Martini (2012) showed that astringent feeling factors and sour basic taste were clustered in the same quadrant. These compounds may provide the link to astringent feeling factors and sour basic taste. A sulfur-containing compound, 2-acetyl

thiazole, entered the stepwise equation for sour basic taste at step 2. Methyl-pyrazine also entered the stepwise equation at step 8, and indicated that as sour basic taste increased, methyl-pyrazine decreased. Thiazoles and pyrazines are usually associated with roasted meat odor (Bueno et al., 2011) and may indicate that the sour basic taste may be a component of roasted meat odor.

Heneicosane entered the stepwise linear regression equation for salty basic taste at step 1 and 3-(1,1-dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol entered the equation at step 2 (Table 15). Other compounds that were predictive of the salty basic taste were 2,3-dimethylbenzaldehyde (step 3), and ethyl-benzene (step 4). Nine out of the 53 compounds in the final equation were aldehydes.

The stepwise linear regression equation for bitter basic taste included compounds used in prediction equations for other attributes (Table 16). For example, 1,2-dimethylpyrrolidine entered the stepwise regression equation for bitter basic taste at step 10 and entered the stepwise linear regression equation for astringent feeling factors at step 1. Additionally, trimethyl-pyrazine was predictive for bitter basic taste at step 7 and was included in the stepwise regression equation for bloody/serumy flavor aromatics (step 6). At high concentrations and when treatments have been cooked for long periods of time over high heat, Maillard reaction products may provide a wide range of flavors, some unpleasant or pleasant, depending on the food matrix.

Partial Least Squares Regression

To better understand the relationship between trained sensory attributes and aromatic categories of compounds as well as the relationship between these variables

and treatments, partial least square regression was performed (Figure 2). Ketones, benzenes, pyrazines, and nitrogen-containing compounds were clustered together in the same quadrant as alkanes, sulfur-containing compounds, and tenderloin medallions cooked to 79.4°C and loin chops cooked to 62.7°C and 68.3°C. Alcohols, aldehydes, furans, and alkenes were clustered in the same quadrant with acids, as well as inside ham chops cooked to 73.8°C and 62.7°C, and loin chops cooked to 79.4°C. Sour basic taste and metallic flavor aromatics and astringent feeling factors were also present in this quadrant. Although the majority of classifications of compounds did not cluster closely with specific treatments or flavor aromatic attributes, Maillard-derived categories, such as nitrogen-containing compounds, pyrazines, and benzenes were clustered together. Tenderloin medallions and inside ham chops cooked to 79.4°C were present in the same quadrant as these classifications since this is the highest degree of doneness that was measured in this study and was exposed to the griddle for a longer time to achieve the internal endpoint temperature. Additionally, in another quadrant, lipid-derived classifications, such as alcohols and aldehydes, clustered together. Metallic flavor aromatics and astringent feeling factors were clustered near inside ham chops cooked to 62.7°C and acids. Sour basic taste and acids were present in the same quadrant as most sour basic tastes are derived from the acids classification (Damodaran et al., 2008). Maughan and Martini (2012) also showed that sour basic taste and metallic flavor aromatics were clustered together.

The relationship between trained sensory attributes and specific aromatic compounds as well as the relationship between these variables and treatments was

determined using the partial least square regression (Figure 3). Some attributes and treatments were related. Pork identity and brown/roasted flavor aromatics were clustered in the same positive quadrant, indicating that brown/roasted flavor aromatics may play a role in pork identity flavor aromatics. Salty, umami, and sweet basic taste, and fat-like flavor aromatics were clustered loosely together in a different quadrant with cardboardy flavor aromatics. It was interesting to see that cardboardy flavor aromatics were present in the same quadrant as basic tastes and fat-like flavor aromatics, since cardboardy flavor aromatics has sometimes been described as an oxidation flavor attribute (Johnson and Civille, 1986; Rhee et al., 2005). Johnson and Civille (1986) determined that cardboardy flavor aromatics were an attribute used to describe warmed-over flavor aromatics. Maughan and Martini (2012) found that, using principal component analysis, brothy and fatty flavor aromatics, and salty basic taste were clustered with pork. However, brothy flavor aromatics were determined to be a separate attribute from umami basic taste and were clustered in a different quadrant. Astringent feeling factors, metallic, bloody/serumy, and liver-like flavor aromatics as well as bitter and sour basic tastes were present in the same quadrant as inside ham chops and tenderloin medallions cooked to 73.8°C, inside ham chops and tenderloin medallions cooked to 62.7°C, and tenderloin medallions and inside ham chops cooked to 68.3°C but opposite the other attributes in a different quadrant. Therefore, as astringent feeling factors, metallic, and bloody/serumy flavor aromatics, and bitter basic taste increased, fat-like and pork identity flavor aromatics decreased. Metallic and bloody/serumy flavor aromatics have been shown to be related (Miller et al., 2014). Maughan and Martini

(2012) showed that bloody and metallic flavor aromatics, and bitter basic taste clustered in the same quadrant, also indicating a negative relationship; however, astringent feeling factors and sour basic taste were clustered in a different quadrant in our study. Glascock (2014) showed that bloody/serumy flavor aromatics were related to cuts that were cooked to lower degrees of doneness. Both inside ham and tenderloin treatments cooked to lower internal endpoint temperatures were located in the same quadrant as sour and bitter basic tastes and astringent feeling factors, metallic, and bloody/serumy flavor aromatics. Additionally, the two lower degrees of doneness for both tenderloin medallions and inside ham chops indicated that there might be a connection between lower internal endpoint cook temperature and these attributes in these treatments. Means separations for the four temperatures showed this trend for these attributes.

Most compounds did not cluster with any treatments or attributes, but some attributes and treatments were related to compounds. Pork identity flavor aromatics and shoulder chops cooked to 73.8°C were clustered with a large number of compounds including butanoic acid, 2,3-dimethylbenzaldehyde, trans, trans-2,4-octadienal, 2,4 heptadienal, (E,E)-2,4-heptadienal, 4-ethyl-benzaldehyde, octadecanal, 2-butylfuran, octane, 2-dodecen-1-ol, 1,1'-oxybis-heptane. Butanoic acid was also related to pork identity flavor aromatics and entered the stepwise regression for pork identity flavor aormatics at step 1. 2,4-heptadienal has been shown to be associated with nut and fat flavors and aromas (Calkins and Hodgen, 2007). Aldehydes have been shown to be flavor potentiators due to their low odor threshold and prevalence as oxidized flavors (Shahidi et al., 2013). Benzaldehyde compounds have been associated with almond oil,

bitter, and burning aromatics (Calkins and Hodgen, 2007) and aldehydes with six to ten carbons are major compounds that play a large role in meat aroma (Mottram, 1998). Mottram (1985) found benzaldehyde in all treatments that were studied with the highest levels being in roasted and lightly grilled treatments. This data may indicate a link between benzaldehyde, pork identity flavor aromatics, and cuts cooked to a higher internal endpoint temperature across all pork products used in Mottram (1985) and the present study. Because of the prevalence of multiple benzaldehyde derivatives as shown across all data, it could partially explain pork identity flavor aromatics and the flavors associated with it. 2,3-dimethylbenzaldehyde was also highly related to umami basic taste ($r=0.54$) and entered the stepwise regression equation for pork identity flavor aromatics at step 16, for brown/roasted flavor aromatics at step 9, and fat-like flavor aromatics at step 1. Benzaldehyde derivatives may explain the effect that umami basic taste could have on pork identity flavor aromatics as the umami basic taste likely provides "meaty" and "brothy" flavor aromatics to a food matrix (Kawamura and Kare, 1987; Adhikari et al., 2011). It was not surprising that many chemical compounds and even other flavor aromatics could be related to pork identity flavor aromatics since pork flavor is complex.

Cardboardy flavor aromatics were loosely clustered with 4-hydroxy-benzoic acid, pentanal, and (1-methylethyl)-benzene. Pentanal has been associated with flavor aromatics such as burnt, green (Shahidi et al., 2013) and almond, malt, pungent, and acrid (Calkins and Hodgen, 2007). Brown/roasted flavor aromatics were loosely clustered with 2,4-decadienal. Aldehydes such as 2,4-decadienal have been found in

pork fat and may play a role in brown/roasted flavor aromatics (Shahidi et al., 2013). Pork identity flavor aromatics were related to 2,4-decadienal in both the simple correlation coefficients and stepwise linear regression equations analyses, which further indicated that brown/roasted and this compound influenced pork identity flavor aromatics and that brown/roasted flavor aromatics may influence the pork identity flavor aromatics. Calkins and Hodgen (2007) stated that this compound was associated with a deep fat flavor and came from the autoxidation of fatty acids such as linoleic and arachidonic acid. They also discussed that 2,4-decadienal had a positive effect on beef flavor, but that there were unknown effects on pork flavor. Maughan and Martini (2012) found that pork was clustered with fatty and browned flavor aromatics in the same quadrant. The partial least square regression did not show the same relationship. The relationship of this compound to these aforementioned attributes in the stepwise regression may explain why they clustered together in Maughan and Martini (2012). Bitter basic taste was loosely clustered with 4-methyl-phenol, which has been shown to be present in pork flavor as well as mutton flavor (Shahidi et al., 2013). This compound also entered the stepwise linear regression equation for metallic flavor aromatics at step 21.

Shoulder chops cooked to 79.4°C were clustered with 2,4-nonadienal, octadecane, and (E)-2-hexenal. 2,4-nonadienal entered the stepwise linear regression equation for astringent feeling factors at step 6 and fat-like flavor aromatics in step 3. Interestingly, trained panelists ranked shoulder chops higher in fat-like flavor aromatics during lexicon validation. Xie et al. (2008) described that 2-hexenal may have green,

rancid or roasted flavor aromatics, which may indicate that, at higher internal endpoint temperatures, 2-hexenal may play a role in roast flavor aromatics. Additionally, 2-hexenal was predictive for bitter basic taste at step 2. Shoulder chops cooked to 62.7°C were closely clustered with 2-decen-1-ol, which entered the stepwise equation for bloody/serumy flavor aromatics at step 1. This was expected since bloody/serumy flavor aromatics have been associated with cuts cooked to lower degrees of doneness (Glascock, 2014). Shoulder treatments, regardless of temperature, were shown to be influenced by lipid oxidation products. Inside ham chops cooked to 62.7°C were closely clustered with 2,5-dimethyl-heptane, which entered the stepwise linear regression equation for bloody/serumy flavor aromatics at step 3. Loin chops cooked to 79.4°C were closely clustered with pentadecane, hexanal, 1-decanol, 1-pentanol, heptanal, and cyclooctane. Heptanal has been shown to have oily, fatty, and rancid flavor aromatics, hexanal has been shown to have fatty-green, grassy, and fat flavor aromatics, and 1-pentanol has been shown to have fusel oil, fruit, and balsamic flavor aromatics (Calkins and Hodgen, 2007). 1-pentanol was found by Mottram (1985) in all samples that were studied, but was slightly higher in lightly grilled and roasted products. Aldehydes and alcohols were shown to be in the same quadrant as this particular treatment, further strengthening the relationship (Figure 2). Inside ham chops cooked to 79.4°C were closely clustered with 2-decanone. Ketones were shown to be in the same quadrant as this treatment (Figure 2). Tenderloin medallions cooked to 79.4°C were closely clustered with several compounds including 4-oxononanal, octenal, dodecanal, 3-dodecen-1-al, (E)-4-dodecene, benzothiazole, N,N'-Dimethylcyclobutane-1,1-

bis(methylamine), 1-tetradecanol, 3-isopropyl-piperidine, (Z)-2-dodecene, formic acid, heptyl ester, and tetradecane. N,N'-Dimethylcyclobutane-1,1-bis(methylamine) was predictive for astringent feeling factors at step 3 and sour basic taste at step 5. Benzothiazole was present in this particular treatment since thiazole quantities have been shown to increase with increasing internal temperature and cook method (Mottram, 1998). Mottram (1985) also found thiazole derivatives in well-done pork samples.

CHAPTER V

CONCLUSIONS

Data from this study indicated that an intact muscle lexicon for pork flavor and aroma was successfully developed and validated as panelists found differences between treatments. Trained panelists determined a total of 24 flavor and aroma attributes that have been defined as the pork flavor lexicon. Pork identity, brown/roasted, bloody/serumy, fat-like, and metallic flavor aromatics, and astringent feeling factors, sweet, sour, salty, and bitter basic tastes were attributes that trained panelists determined to be present in pork most frequently.

Lexicon validation showed that, overall, all pork samples had moderate levels of pork identity flavor aromatics and umami basic taste. Liver-like, nutty, and fat-like flavor aromatics were not present at high levels. Some of the attributes were not detected during lexicon validation. Shoulder chops were ranked higher in pork identity and fat-like flavor aromatics and lower in umami basic taste. Loin chops and shoulder chops were slightly higher in brown/roasted flavor aromatics. Loin chops and inside ham chops were slightly higher in sour basic taste, and inside ham chops were slightly higher in astringent feeling factors and metallic flavor aromatics, and sour basic taste. As internal endpoint temperatures increased, brown/roasted flavor aromatics increased, while bloody/serumy flavor aromatics and astringent feeling factors, and sour and bitter basic tastes decreased.

Compound classes that contributed to pork flavor were sulfur-containing

compounds, nitrogen-containing compounds, aldehydes, ketones, acids, alkanes, alkenes, furans, pyrazines, and benzenes. Aldehydes influenced many attributes, as their levels were quantitatively much higher than other compound classes. Treatments also varied widely in the number and type of aromatic compounds clustering with treatments. Cuts that were shown to be higher in attributes that were indicative of lower internal endpoint temperatures, such as inside ham chops, clustered with alkanes and alcohols. Shoulder chops cooked to a higher internal endpoint temperature clustered with aldehydes and benzaldehydes. Regardless of internal endpoint temperature across cuts, aldehydes and alcohols clustered with treatments, indicating that lipid oxidation products may play a large role in pork flavor research.

Additional research and lexicon validation needs to be done using the pork lexicon to ensure consistency within the meat research community. This would allow researchers to better communicate about pork flavor since all meat scientists would be using the same language and ranking scale. Further studies comparing flavor aromatic compounds of various retail pork cuts by examining the differences in muscle myology as well as the effects of fatty acid level, myoglobin content, non-heme iron levels, and fat and moisture levels may be needed to further understand what drives pork flavor. Looking more closely at specific compounds that were most predictive and supported by other data may help researchers to understand the specific compounds that influence specific flavor and aroma attributes. Aromatic compounds clearly influenced specific flavor aromatic attributes as defined by the trained panelists from lexicon development and validation. Utilization of the GC-O and the Aroma-Trax program could be helpful

in specifically identifying odor-active compounds that are responsible for each attribute by using the intensity and attribute functions within the program.

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APPENDIX A

TABLES

Table 1. Sample descriptions, muscle categories, cooking methods and endpoint temperatures used in the lexicon development.

Treatment	Cut	Samples (n)
Cook Methods		
Braising	Roasts	7
Roasting	Roasts	12
Grilling	Chops/Medallions	48
Endpoint Temperatures		
62.7°C	Roasts	19
57.2°C	Chops/Medallions	18
68.3°C	Chops/Medallions	19
79.4°C	Chops/Medallions	16
Muscle categories		
Shoulder	Chops	4
	Roasts	3
Picnic	Roasts	1
Tenderloin	Medallions	8
	Roasts	4
Bellies	Roasts	7
Fresh Ham Leg	Roasts	2
Loin	Chops	22
	Roasts	2
Conditions		
Boar Taint	Chops	3
	Ground	2
Sow	Ground	2
Enhanced	Chops	7
	Roasts	1
Packaging	Chops	18
PVC		
MAP		
Vacuum		
Spoiled/Putrid	Chops	1
	Ground	1
Warmed-Over	Ground	3
	Chops	3
Refrigerator Stale	Chops	5
	Ground	4
Long Frozen	Chops	8

Table 2. Definitions and references for pork flavor attributes, where 0 = none and 15 = extremely intense.

Attribute	Definition	Reference
Basic Tastes		
Bitter	The fundamental taste factor associated with a caffeine solution	0.05% caffeine in 1000 mL water = 2.0 (F) 0.08% caffeine in 1000mL water = 5.0 (F)
Salty	The fundamental taste factor of which sodium chloride is typical	0.2% Salt in 1000mL water = 2.5 (F) 0.35% Salt in 1000mL water = 5.0 (F)
Sour	The fundamental taste factor associated with citric acid solution	0.05% Citric Acid in 1000mL water = 2.0 (F) 0.08% Citric Acid in 1000mL water = 5.0 (F)
Sweet	The fundamental taste factor associated with a sucrose solution	0.05% Sugar in 1000mL water = 2.0 (F) 0.08% Sugar in 1000mL water = 5.0 (F)
Umami	Flat, salty, somewhat brothy. The taste of glutamate, salts of amino acids and other molecules called nucleotides.	0.035% Accent flavoring in 1000mL water = 7.5 (F)
Flavor Aromatics		
Boar Taint	Aromatic associated with boar taint; hormone-like; sweat, animal urine	0.1g 3-methylindole, sniffed = 13.0 (A) Androstenone wafted directly from bottle = 15.0 (A)
Bloody/ Serumy	An aromatic associated with blood on cooked meat products; closely related to metallic aromatic	Boneless Pork Chop, 135°F = 2.0 (F&A)
Brown/ Roasted	A round, full aromatic generally associated with pork suet that has been broiled	Pork Fat, cooked and browned= 3.0 (F), 4.0 (A)
Burnt	The sharp/acrid flavor note associated with over roasted pork muscle, something over baked or excessively browned in oil	Arrowhead Barley Cereal, 7-10 puffs = 3.0 (F&A)
Cardboardy	Aromatic associated with slightly oxidized fats and oils, reminiscent of wet cardboard packaging	Dry cardboard, 1 in square = 5.0 (F), 3.0 (A) Wet cardboard, 1 in square steeped in 1 cup water for 30 min = 7.0 (F), 6.0 (A)
Chemical	Aromatic associated with garden hose, hot Teflon pan, plastic packaging and petroleum-based products such as charcoal lighter fluid	1 drop Clorox in 200 mL water = 6.5 (F) Ziploc Bag in snifter = 13.0 (A)
Fat-Like	Aromatics associated with cooked animal fat	Pork Fat, cooked and browned= 10.0 (F); 7.0 (A)
Floral	Sweet, light, slightly perfume impression associated with flowers	0.12 oz Clorox Wipe Liquid in 4 oz water= 8.0 (A) Geraniol, 2 drops on cotton ball in snifter = 7.5 (A) 1:1 White Grape Juice to Water = 5.0 (F&A)
Heated Oil	The aromatics associated with oil heated to a high temperature	Wesson Oil, microwaved 3 min = 7.0 (F&A) Lay's Potato Chips = 4.0 (A)

Table 2 (Continued).

Attribute	Definition	Reference
Liver-Like	Aromatics associated with cooked organ meat/liver	Pork Liver, 71°C= 15.0 (F); 12.0(A)
Metallic	The impression of slightly oxidized metal, such as iron, copper, and silver spoons	Dole Pineapple Juice = 6.0 (A&F) 0.10% KCl in 1L water = 1.5 (A&F)
Nutty	Nutty characteristics are: sweet, oily, light brown, slightly musty and/or buttery, earthy, woody, astringent, bitter, etc.	Diamond Shelled Walnut, ground for 1 min= 6.5 (F)
Pork Identity	Amount of pork flavor identity in the sample	Boneless Pork Chop, 175°F = 7.0 (F), 5.0 (A) 80/20 Ground Pork, 71°C= 6.0 (F); 5.0 (A)
Refrigerator Stale	Aromatics associated with products left in the refrigerator for an extended period time and absorbing a combination of odors (lack of freshness/flat)	80/20 Ground Pork, 71°C, left chilled overnight, served room temperature = 6.0 (F), 8.0 (A)
Soapy	An aromatic commonly found in unscented hand soap	0.12 oz Clorox Wipe Liquid in 4 oz water= 3.0 (A) 0.5g Ivory Bar Soap in 100mL water = 6.5 (A)
Spoiled/Putrid	The presence of inappropriate aromatics and flavors that is commonly associated with the products. It is a foul taste and/or smell that indicates product is starting to decay and putrefy.	Boneless Pork Chop room temperature raw for 24 hours, refrigerate for 6 days, 175°F, smelled only = 3.0 (A) 80/20 Ground Pork, same as above, 71°C = 5.0 (A)
Vinegary	Aroma notes associated with vinegar	1.1g Vinegar in 200g water = 6.0 (F); 4.0 (A)
Warmed-Over	Perception of a product that has been previously cooked and reheated	80/20 Ground Pork, cooked to 71°C, left chilled overnight and microwaved for 1 min = 5.0 (F&A)
Mouthfeels		
Astringent	The chemical feeling factor on the tongue or other skin surfaces of the oral cavity described as a puckering/dry and associated with tannins or alum	Lipton Tea, 1 bag in 1 cup boiling water and steeped for 3 min= 6.0 (F) Lipton Tea, 3 bags in 1 cup boiling water and steeped for 3 min = 12.0 (F)

Table 3. Pork flavor attribute (0=none; 15=extremely intense) least squares means for pork cuts and degrees of doneness using the Pork Lexicon.

	Pork	Brown/	Fat-	Bloody/		Atrin-	Basic Tastes					Liver-	
Effects	Identity	Roasted	Like	Serumy	Metallic	gent	Sweet	Sour	Salty	Bitter	Umami	Like	Nutty
P – value[d]	<0.0001	0.002	<0.0001	0.02	0.004	0.02	<0.0001	0.001	<0.0001	0.08	<0.0001	0.01	0.02
Cuts													
Tenderloin	5.5[a]	0.6[a]	0.4[b]	1.1[ab]	1.9[a]	1.8[ab]	0.3[b]	1.8[ab]	1.1[a]	1.9	0.1[a]	0.1[c]	0.0[a]
Loin	5.6[a]	1.1[b]	0.3[a]	0.9[a]	2.0[a]	1.7[a]	0.2[a]	2.0[bc]	1.1[a]	1.8	0.1[a]	0.0[a]	0.0[a]
Ham	5.6[a]	0.8[ab]	0.5[b]	1.4[b]	2.2[b]	1.9[b]	0.3[ab]	2.1[c]	1.2[a]	2.0	0.1[a]	0.1[bc]	0.1[ab]
Shoulder	6.0[b]	1.0[b]	1.2[c]	1.3[ab]	2.0[a]	1.7[a]	0.7[c]	1.6[a]	1.4[b]	1.9	0.4[b]	0.0[ab]	0.1[b]
Cooked Internal Temperature Endpoint													
P – value[d]	0.19	0.007	0.60	<0.0001	0.001	0.01	0.88	0.009	0.11	0.007	0.09	0.08	0.97
62.7°C	5.6	0.6[a]	0.6	1.7[b]	2.2[b]	1.9[b]	0.3	2.1[c]	1.1	2.0[b]	0.1	0.1	0.1
68.3°C	5.7	0.8[ab]	0.5	1.5[b]	2.1[b]	1.8[b]	0.4	2.0[bc]	1.2	2.0[b]	0.2	0.1	0.1
73.8°C	5.7	1.0[b]	0.6	0.9[a]	2.0[b]	1.8[ab]	0.4	1.8[ab]	1.3	1.9[ab]	0.3	0.1	0.1
79.4°C	5.7	1.1[b]	0.6	0.8[a]	1.9[a]	1.6[a]	0.4	1.7[a]	1.2	1.8[a]	0.2	0.0	0.1
RMSE[e]	0.31	0.48	0.31	0.49	0.26	0.24	0.20	0.39	0.20	0.26	0.18	0.11	0.14

[abc]Mean values within a column followed by the same letter are not significantly different (P > 0.05)

[d]*P* - value from analysis of variance tables.

[e]Root Mean Square Error

Table 4. Overall means and standard deviation values for volatile, aromatic chemicals identified by the GC/MS.

Code:	Volatile, Aromatic Chemical	Retention Time (min)	n	Mean	Standard Deviation	Classification
c1:	2-Octenal	17.05	94	109265	145707	Aldehyde
c2:	2,4-Nonadienal	21.46	94	21800	34401	Aldehyde
c3:	3-Octanone	14.83	94	10531	101156	Ketone
c4:	5-Pentyl-2(5H)-furanone	25.84	94	2325	10591	Ketone; Furan
c6:	Acetophenone	18.98	94	1768	8484	Ketone; Benzene
c7:	Benzaldehyde	16.31	94	443717	573934	Aldehyde; Benzene
c8:	3-Ethyl-benzaldehyde	20.86	94	11947	25394	Aldehyde; Benzene
c9:	Decanal	20.19	94	43786	47202	Aldehyde
c10:	Dodecane	19.28	94	84600	210648	Alkane
c11:	2-Pentyl-furan	14.35	94	276989	427206	Furan
c12:	Hexanoic acid	20.21	94	39400	52999	Acid
c13:	N-heptanal	12.22	94	283511	480526	Aldehyde
c14:	Nonanal	17.65	94	1740909	1315541	Aldehyde
c15:	Nonenal	19.45	94	48843	58981	Aldehyde
c16:	Octanal	15.13	94	1052276	1023654	Aldehyde
c17:	Phenol	22.55	94	16309	31885	Alcohol; Benzene
c18:	Phenyl acetaldehyde	18.54	94	17830	23341	Aldehyde; Benzene
c19:	Styrene	12.53	94	21701	24503	Alkene; Benzene
c20:	1-Heptanol	15.39	94	87992	109241	Alcohol
c21:	(E)-2-decenal	22.01	94	86144	108868	Aldehyde
c22:	2,3-Octanedione	14.73	94	200898	18884430	Ketone
c23:	2,4-Decadienal	23.00	94	32790	106359	Aldehyde
c24:	Hexanal	9.40	94	2941517	3072000	Aldehyde
c25:	3-Isopropyl-piperidine	18.25	94	532.8	4232	Nitrogen

Table 4 (Continued).

Code:	Volatile, Aromatic Chemical	Retention Time (min)	n	Mean	Standard Deviation	Classification
c26:	Tridecanal	24.51	94	3745	13541	Aldehyde
c27:	Undecenal	24.21	94	16643	45508	Aldehyde
c29:	1-Octanol	17.78	94	59376	153121	Alcohol
c30:	1-Octen-3-ol	15.47	94	111734	288139	Alcohol
c32:	2-Dococen-1-al	22.30	94	9146	29409	Aldehyde
c33:	(E)-2-nonenal	19.56	94	21073	50326	Aldehyde
c34:	1,3-Bis (1,1-dimethylethyl)-benzene	20.76	94	41972	70681	Benzene
c35:	Benzothiazole	23.83	94	5300	16038	Benzene; Nitrogen; Sulfur
c37:	Dl-limonene	15.22	94	8853	31428	Alkene
c38:	Heptanal	12.31	94	300203	606609	Aldehyde
c40:	4-Methyl-phenol	23.83	94	8536	23315	Alcohol; Benzene
c41:	2,5-Dimethyl-pyrazine	13.55	94	36419	66333	Pyrazine; Nitrogen
c42:	3-Ethyl-2,5-dimethyl-pyrazine	17.45	94	11658	24209	Pyrazine; Nitrogen
c43:	Tridecane	21.16	94	5532	21641	Alkane
c44:	1-Octen-3-ol	15.46	94	233775	414964	Alcohol
c45:	1-Octen-3-one	14.49	94	22976	51396	Ketone
c46:	1-Pentanol	10.22	94	55901	111844	Alcohol
c47:	2-Methylene cyclopentanol	21.81	94	1518	10519	Alcohol; Alkene
c48:	3-Dodecen-1-al	23.80	94	28286	82120	Aldehyde
c50:	Benzene acetaldehyde	18.56	94	6728	21122	Aldehyde; Benzene
c51:	1-(1H-pyrrol-2-yl)-ethanone	22.43	94	1725	9439	Ketone; Nitrogen
c52:	N-caproic acid, vinyl ester	15.39	94	60120	206785	Acid
c54:	Nonanoic acid	20.38	94	1103	7542	Acid
c55:	2-Ethyl-5-methyl-pyrazine	15.69	94	3496	11183	Pyrazine; Nitrogen

Table 4 (Continued).

Code:	Volatile, Aromatic Chemical	Retention Time (min)	n	Mean	Standard Deviation	Classification
c57:	2-Ethyl-6-methyl-pyrazine	15.65	94	625.1	3823	Pyrazine; Nitrogen
c58:	Trimethyl-pyrazine	15.80	94	27520	53188	Pyrazine: Nitrogen
c60:	1-Hexanol	12.82	94	16690	1568866	Alcohol
c61:	1-Pyrrolidine carboxaldehyde	18.83	94	905.4	4007	Aldehyde; Nitrogen
c63:	(E)-2-octen-1-ol	18.23	94	13602	44767	Alcohol
c64:	2,4 Decadienal	23.74	94	4285	17851	Aldehyde
c65:	2,4 Heptadienal	16.70	94	2278	14852	Aldehyde
c66:	Octanoic acid	21.41	94	4125	28769	Acid
c67:	Pentanal	8.32	94	18559	60489	Aldehyde
c69:	2-Ethyl-3,5-dimethyl-pyrazine	17.55	94	1351	5252	Pyrazine; Nitrogen
c72:	2-Acetyl thiazole	18.28	94	2771	10139	Nitrogen; Sulfur
c73:	2-Butylfuran	11.73	94	2141	14605	Furan
c74:	2-Heptanone	12.00	94	16528	42887	Ketone
c75:	(E)-2-heptenal	14.40	94	40494	115477	Aldehyde
c77:	1-Methyl-4-(1-methylethyl)-benzene	15.64	94	1630	11938	Benzene
c79:	2-Ethyl-1-hexanol	16.61	94	1232	8698	Alcohol
c80:	(E)-2-hexenal	12.28	94	7618	24899	Aldehyde
c82:	(E)-2-octenal	17.01	94	68215	145413	Aldehyde
c83:	1-Propoxy-2-propanol	11.30	94	2134	11617	Alcohol
c84:	2,5-Octanedione	14.80	94	264184	103573	Ketone
c86:	Ethyl-benzene	8.41	94	1080	6150	Benzene
c87:	Hexadecane	19.89	94	1508	7500	Alkane
c90:	Methyl-pyrazine	11.43	94	2133	15453	Pyrazine; Nitrogen
c91:	6-Methyl-2-heptanone	14.42	94	1743	7552	Ketone

Table 4 (Continued).

Code:	Volatile, Aromatic Chemical	Retention Time (min)	n	Mean	Standard Deviation	Classification
c92:	1-(4,5-Dihydro-2-thiazolyl)-ethanone	20.47	94	512.7	2940	Ketone; Nitrogen; Sulfur
c94:	Octane	8.29	94	1284	10411	Alkane
c97:	1,2-Benzisothiazole	23.84	94	1285	8990	Benzene; Nitrogen; Sulfur
c98:	2,3-Dimethylbenzaldehyde	20.90	94	347.4	2562	Aldehyde; Benzene
c99:	4-Octen-3-one	17.62	94	927.7	4050	Ketone
c100:	Benzophenone	18.94	94	812.0	4308	Ketone; Benzene
c101:	Heptanoic acid	20.23	94	2005	10910	Acid
c102:	Heptenal	14.47	94	2337	9307	Aldehyde
c103:	Nonadecane	19.25	94	1502	6104	Alkane
c105:	Tetradecanal	24.96	94	10243	27624	Aldehyde
c109:	1-Phenyl-ethanone	18.98	94	7313	21535	Ketone; Benzene
c110:	Trans-2-undecen-1-ol	18.28	94	1924	10540	Alcohol
c111:	Undecanal	22.53	94	1848	9009	Aldehyde
c112:	1-Decanol	17.90	94	537.4	3683	Alcohol
c114:	Octadecane	23.50	94	982.4	4251	Alkane
c116:	Tetradecane	16.07	94	5983	32892	Alkane
c117:	3-Ethyl-2-methyl-1,3-hexadiene	16.55	94	25330	57996	Alkene
c118:	2,4 Nonadienal	21.48	94	1664	8689	Aldehyde
c119:	Acetic acid	13.16	94	4534	14191	Acid
c120:	Hentriacontane	19.23	94	1085	5015	Alkane
c121:	[(Dodecyloxy)methyl]-oxirane	16.61	94	670.0	4581	Alkane
c122:	Cyclooctyl alcohol	18.30	94	1557	9141	Alcohol
c123:	Heneicosane	19.98	94	439.1	3014	Alkane

Table 4 (Continued).

Code:	Volatile, Aromatic Chemical	Retention Time (min)	n	Mean	Standard Deviation	Classification
c124:	2,5-Dimethyl-heptane	14.91	94	2091	15502	Alkane
c128:	Trans, trans-2,4-octadienal	19.64	94	1644	8601	Aldehyde
c129:	2-Dodecen-1-ol	18.34	94	685.7	4957	Alcohol
c131:	1-[2-(2-Methylbutyl)phenyl]ethanone	20.84	94	5004	27058	Ketone; Benzene
c132:	(E,E)-2,4-heptadienal	16.55	94	3208	12116	Aldehyde
c133:	4-Ethyl-benzaldehyde	20.82	94	1852	12721	Aldehyde; Benzene
c134:	1,1'-Oxybis-heptane	15.44	94	6138	46636	Alkane
c135:	1-Tetradecanol	16.81	94	433.5	3217	Alcohol
c138:	1,2-Dimethylpyrrolidine	25.83	94	862.1	5883	Nitrogen
c139:	2-butyl-2-octenal	23.71	94	608.8	4161	Aldehyde
c140:	N,N'-bis (3-aminopropyl)-1,3-propanediamine	17.14	94	440.6	2610	Alkane; Nitrogen
c141:	Ethylidene cycloheptane	16.64	94	1399	9549	Alkane
c144:	Heptanol	15.27	94	2863	16081	Alcohol
c145:	(1-Methylbutyl)-oxirane	12.83	94	1370	8207	Alkane
c147:	4-Oxononanal	22.77	94	357.8	2520	Aldehyde
c150:	Pentadecane	22.57	94	1707	6575	Alkane
c151:	Trans-2-tridecenal	22.71	94	3389	20960	Aldehyde
c152:	Dodecanal	22.57	94	10905	48985	Aldehyde
c154:	Octadecanal	25.07	94	1305	8954	Aldehyde
c155:	2,3,5-Trimethyl pyrazine	15.82	94	7151	29537	Pyrazine; Nitrogen
c158:	(Z)-2-dodecene	19.55	94	771.7	5758	Alkene
c159:	(E)-4-dodecene	19.15	94	1055	8748	Alkene
c160:	Nonacosane	20.70	94	186.7	1279	Alkane
c161:	Hexadecanal	20.70	94	325.6	2228	Aldehyde
c162:	1,1-Bis(dodecyloxy)-hexadecane	22.54	94	339.7	2514	Alkane

Table 4 (Continued).

Code: Volatile, Aromatic Chemical	Retention Time (min)	n	Mean	Standard Deviation	Classification
c163: Cyclooctane	17.74	94	19517	84798	Alkane
c164: 2-Decanone	19.01	94	773.4	4815	Ketone
c166: Cycloheptane	16.49	94	2663	18550	Alkane
c167: 2-Nonanone	17.75	94	941.9	6638	Ketone
c170: 3-(1,1-Dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol	14.82	94	3015	24167	Alcohol
c171: Butanoic acid	16.60	94	3955	22509	Acid
c172: Octenal	16.91	94	4984	34138	Aldehyde
c173: 1,3,5,7-Cyclooctatetraene	12.58	94	848.7	5792	Alkene
c174: 4-(2-Propenyl)-1H-imidazole	21.34	94	1688	8734	Nitrogen
c175: Chavicol	20.87	94	466.4	3000	Alcohol; Benzene
c177: Formic acid, heptyl ester	15.35	94	757.6	6468	Acid
c182: 6,7-Dodecanedione	14.63	94	7190	53584	Ketone
c183: Cyclooctanol	18.23	94	2321	13066	Alcohol
c184: 3-(Methylthio)-propanal	14.76	94	1025	6344	Aldehyde; Sulfur
c185: 2-Methyl-3-octanone	14.81	94	8308	76339	Ketone
c186: 2-Dodecenal	24.24	94	999.2	6899	Aldehyde
c188: Dihydro-2(3H)-furanone	17.20	94	4073	31030	Ketone; Furan
c189: 2-Ethyl-cyclobutanone	10.21	94	590.7	4297	Ketone
c190: Nitro-L-arginine	20.94	94	470.1	3241	Nitrogen
c192: 3-(1,1-Dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol,	14.94	94	3141	24889	Alcohol
c194: Decane	17.88	94	506.7	3473	Alkane
c196: 3-Methyl-butanal	11.33	94	1959	13433	Aldehyde
c197: (E,E)-2,4-Octadienal	19.02	94	1316	7460	Aldehyde

Table 4 (Continued).

Code: Volatile, Aromatic Chemical	Retention Time (min)	n	Mean	Standard Deviation	Classification
c198: Phenyl-oxirane	18.60	94	1146	5740	Alkane; Benzene
c202: 2-Heptanone	11.96	94	1192	8439	Ketone
c203: Formic acid, hexyl ester	12.87	94	1215	8547	Acid
c205: Delta.-(2)-dodecanol	18.30	94	2239	16531	Alcohol
c207: Undecane	16.58	94	693.4	5126	Alkane
c208: N,N'-Dimethylcyclobutane-1,1-bis(methylamine)	26.47	94	580.8	3961	Alkane; Nitrogen
c210: 2-decen-1-ol	18.29	94	1400	9549	Alcohol
c212: (1-methylethyl)-benzene	12.67	94	776.4	5494	Benzene
c214: 4-hydroxy-benzoic acid	22.72	94	470.3	3249	Acid; Benzene
c215: Propyl-propanedioic acid	21.69	94	950.4	4729	Acid
c217: Cyclooctene	18.19	94	3839	29527	Alkene
c219: 3-(4-Tertiobutylphenyl)-propanal	20.85	94	4118	28426	Aldehyde
c220: Trans-2-undecenal	24.39	94	863.6	6200	Aldehyde
c221: 4-Hydroxymandelic acid	16.72	94	2285	16744	Acid

Table 5. Flavor aromatic compound categories least squares means for pork cuts and degrees of doneness.

Effects	Sulfur-Containing	Nitrogen-Containing	Aldehydes	Alcohols	Ketones	Acids	Alkanes
Cut							
P – value[d]	0.004	<0.0001	0.02	0.04	0.01	0.50	0.07
Tenderloin	18551.8[b]	49558.6[a]	6712898.8[a]	589989.3[ab]	286166.4[ab]	134313.7	276597.1
Loin	20493.9[b]	237873.3[c]	8319270.2[ab]	835753.7[b]	451037.7[b]	138311.3	111458.9
Ham	-1626.4[a]	125690.5[b]	9888075.3[b]	861914.6[b]	424764.6[b]	177232.6	79794.4
Shoulder	8637.3[ab]	30932.8[a]	5643161.4[a]	315316.9[a]	159087.1[a]	75904.5	78776.7
Cooked Internal temperature Endpoint							
P – value[d]	0.90	0.62	0.03	0.15	0.21	0.03	0.47
62.7°C	11078.6	101941.2	9516677.0[b]	973698.8	367622.4	268133.5[b]	171382.3
68.3°C	11832.1	112014.7	4928411.9[a]	465215.5	196914.0	62127.1[a]	58525.5
73.8°C	9188.0	93643.0	8038629.2[b]	551017.1	389716.8	96872.7[a]	130978.8
79.4°C	13957.9	136456.3	8079687.6[b]	613043.2	366802.7	98628.7[a]	185740.4
RMSE[e]	20548.64	112421.6	4656991	687462.9	3165831.7	216975.8	270249.0

[abc]Mean values within a column followed by the same letter are not significantly different (P > 0.05)

[d]*P* - value from analysis of variance tables.

[e]Root Mean Square Error

Table 5 (Continued).

Effects	Alkenes	Furans	Pyrazines	Benzenes
P – value[d]	0.24	0.22	<0.0001	0.02
Cuts				
Tenderloin	65669.5	231076.7	20778.4[a]	716338.0[b]
Loin	89294.3	309351.6	213443.2[c]	764880.0[b]
Ham	71958.9	441924.9	121999.6[b]	678713.8[b]
Shoulder	30001.3	205040.7	15666.3[a]	270997.8[a]
Cooked Internal Temperature Endpoint				
P – value[d]	0.05	0.13	0.94	0.96
62.7°C	117384.1	462800.4	88900.0	618075.2
68.3°C	32379.4	143045.9	95458.7	635373.4
73.8°C	45399.0	299105.8	83520.0	627516.9
79.4°C	61761.6	282441.9	104008.9	549964.1
RMSE[e]	94674.56	399453.8	113301.7	545616.4

[abc]Mean values within a column followed by the same letter are not significantly different (P > 0.05)

[d]*P* - value from analysis of variance tables.

[e]Root Mean Square Error

Table 6. Simple correlation coefficients[a] between trained descriptive sensory attributes and volatiles.

Effect	Pork Identity	Brown/ Roasted	Fat-Like	Bloody/ Serumy	Metallic	Astringent
c1 2-Octenal	-0.18	-0.18	0.07	0.10	0.05	0.09
c2 2,4-Nonadienal	0.11	-0.06	0.22	-0.03	-0.30	-0.15
c3 3-Octanone	-0.13	-0.05	-0.04	0.00	-0.02	-0.06
c4 5-Pentyl-2(5H)-furanone	0.19	0.19	0.02	-0.13	-0.09	-0.16
c6 Acetophenone	0.02	-0.08	-0.11	0.00	0.11	0.08
c7 Benzaldehyde	-0.19	-0.08	-0.22	-0.04	0.01	0.05
c8 3-Ethyl-benzaldehyde	0.06	-0.10	-0.02	-0.03	-0.10	-0.01
c9 Decanal	-0.09	0.03	-0.21	-0.13	0.02	0.03
c10 Dodecane	-0.10	-0.11	-0.16	-0.09	0.07	0.06
c11 2-Pentyl-furan	-0.17	-0.06	-0.19	-0.01	0.12	0.08
c12 Hexanoic acid	-0.02	-0.03	-0.02	0.09	0.19	0.14
c13 N-heptanal	0.05	-0.01	0.06	0.10	0.17	0.18
c14 Nonanal	-0.25	-0.22	-0.19	0.09	0.19	0.19
c15 Nonenal	-0.02	-0.04	-0.04	0.03	-0.05	0.06
c16 Octanal	-0.22	-0.19	-0.06	0.11	0.18	0.19
c17 Phenol	0.11	0.15	-0.03	-0.13	-0.17	-0.22
c18 Phenyl acetaldehyde	0.01	0.27	-0.04	-0.05	-0.03	-0.05
c19 Styrene	-0.02	0.11	-0.17	-0.05	-0.04	-0.01
c20 1-Heptanol	-0.26	-0.26	-0.03	0.26	0.22	0.25
c21 (E)-2-decenal	0.09	-0.04	0.16	-0.05	-0.22	-0.14
c22 2,3-Octanedione	-0.22	-0.14	-0.05	0.06	0.08	0.09
c23 2,4-Decadienal	0.29	0.17	0.19	-0.16	-0.36	-0.27
c24 Hexanal	-0.02	0.02	-0.15	-0.01	0.16	0.06

Table 6 (Continued).

Effect	Pork Identity	Brown/ Roasted	Fat-Like	Bloody/ Serumy	Metallic	Astringent
c25 3-Isopropyl-piperidine	-0.06	-0.03	-0.03	-0.03	-0.10	-0.13
c26 Tridecanal	0.10	0.21	0.00	-0.05	-0.01	-0.02
c27 Undecenal	0.14	0.09	0.04	0.06	-0.08	-0.07
c29 1-Octanol	-0.00	0.04	-0.00	-0.05	0.04	-0.00
c30 1-Octen-3-ol	-0.09	-0.09	-0.07	-0.02	0.03	0.04
c32 2-Dococen-1-al	-0.04	-0.02	-0.10	-0.02	0.07	0.10
c33 (E)-2-nonenal	-0.02	-0.07	0.09	0.02	0.06	-0.02
c34 1,3-Bis (1,1-di-methylethyl)-benzene	-0.11	-0.08	-0.25	-0.07	0.02	0.06
c35 Benzothiazole	-0.16	0.04	-0.08	-0.15	-0.23	-0.11
c37 Dl-limonene	-0.05	0.10	-0.04	-0.00	0.12	0.04
c38 Heptanal	-0.20	-0.11	-0.09	0.06	0.13	0.05
c40 4-Methyl-phenol	-0.05	-0.09	-0.00	0.20	0.07	0.10
c41 2,5-Dimethyl-pyrazine	0.18	0.24	-0.17	-0.19	-0.03	-0.05
c42 3-Ethyl-2,5-dimethyl-pyrazine	0.19	0.30	-0.19	-0.23	-0.08	-0.10
c43 Tridecane	0.03	-0.04	0.01	-0.12	0.02	0.01
c44 1 Octen 3 ol	-0.23	-0.12	-0.13	0.00	0.07	0.08
c45 1-Octen-3-one	-0.03	0.05	-0.15	-0.02	0.10	0.05
c46 1-Pentanol	0.32	-0.07	-0.11	-0.08	0.04	-0.06
c47 2-Methylene cyclo-pentanol	0.07	0.02	-0.08	-0.11	-0.06	-0.07
c48 3-Dodecen-1-al	0.10	-0.02	0.09	-0.11	-0.27	-0.20

Table 6 (Continued).

Effect	Pork Identity	Brown/ Roasted	Fat-Like	Bloody/ Serumy	Metallic	Astringent
c50 Benzene acetaldehyde	0.12	0.24	-0.16	-0.06	0.13	0.06
c51 1-(1H-pyrrol-2-yl)-ethanone	-0.00	0.18	-0.06	0.06	0.15	0.07
c52 N-caproic acid vinyl ester	-0.12	-0.15	-0.12	0.03	0.08	0.08
c54 Nonanoic acid	0.08	0.03	-0.06	-0.06	-0.02	0.07
c55 2-Ethyl-5-methyl-pyrazine	0.15	0.27	-0.17	-0.13	-0.04	-0.08
c57 2-Ethyl-6-methyl-pyrazine	0.13	0.17	-0.11	-0.07	-0.02	-0.01
c58 Trimethyl-pyrazine	0.11	0.25	-0.19	-0.22	-0.09	-0.10
c60 1-Hexanol	-0.13	-0.04	-0.04	0.02	0.08	0.05
c61 1-Pyrrolidine carbox-aldehyde	-0.06	-0.17	0.17	-0.01	-0.16	-0.13
c63 (E)-2-octen-1-ol	-0.18	-0.09	-0.12	0.02	0.07	0.01
c64 2,4 Decadienal	-0.04	-0.16	-0.07	0.04	0.06	-0.03
c65 2,4 Heptadienal	0.02	-0.03	0.21	0.03	0.01	-0.10
c66 Octanoic acid	-0.12	-0.05	-0.02	-0.02	-0.01	-0.06
c67 Pentanal	0.03	0.00	0.09	-0.01	-0.03	-0.09
c69 2-Ethyl-3,5-di-methyl-pyrazine	-0.13	-0.07	-0.06	0.09	0.00	0.03
c72 2-Acetyl thiazole	-0.09	0.01	-0.14	0.18	0.11	0.16
c73 2-Butylfuran	-0.07	-0.06	0.12	0.06	0.09	-0.04
c74 2-Heptanone	-0.07	0.08	-0.16	-0.06	0.10	0.12

Table 6 (Continued).

Effect	Pork Identity	Brown/ Roasted	Fat-Like	Bloody/ Serumy	Metallic	Astringent
c75 (E)-2-heptenal	-0.08	-0.08	0.22	0.06	0.04	-0.09
c77 1-Methyl-4-(1-methylethyl)-benzene	0.21	0.08	-0.01	-0.08	-0.02	0.01
c79 2-Ethyl-1-hexanol	-0.09	0.19	-0.08	0.07	0.08	0.15
c80 (E)-2-hexenal	-0.08	-0.09	0.08	-0.00	0.09	-0.00
c82 (E)-2-octenal	0.07	0.05	-0.07	-0.07	-0.02	-0.05
c83 1-Propoxy-2-propanol	0.07	0.15	0.01	-0.02	0.07	0.08
c84 2,5-Octanedione	0.04	0.18	-0.08	-0.05	-0.05	0.04
c86 Ethyl-benzene	0.08	0.15	0.01	-0.01	0.06	0.05
c87 Hexadecane	-0.01	-0.09	-0.04	0.07	0.10	0.01
c90 Methyl-pyrazine	0.02	0.05	-0.09	-0.06	-0.07	-0.10
c91 6-Methyl-2-heptanone	-0.25	-0.26	-0.05	0.08	0.09	0.06
c92 1-(4,5-Dihydro-2-thiazolyl)-ethanone	-0.27	-0.01	-0.03	0.12	-0.05	0.06
c94 Octane	0.22	0.11	0.04	-0.10	-0.10	-0.06
c97 1,2-Benzisothiazole	0.14	0.08	0.19	-0.09	-0.05	-0.07
c98 2,3-Dimethylbenz-aldehyde	0.19	0.19	0.38	-0.13	-0.05	-0.11
c99 4-Octen-3-one	0.26	0.22	0.08	-0.05	-0.08	-0.03
c100 Benzophenone	0.03	0.14	-0.03	-0.02	0.03	-0.05
c101 Heptanoic acid	-0.15	-0.06	-0.06	-0.09	-0.07	-0.08
c102 Heptenal	0.10	0.08	0.06	-0.11	-0.18	-0.08
c103 Nonadecane	-0.03	0.12	-0.03	-0.09	-0.14	-0.01

Table 6 (Continued).

Effect	Pork Identity	Brown/ Roasted	Fat-Like	Bloody/ Serumy	Metallic	Astringent
c105 Tetradecanal	-0.11	0.07	0.03	-0.07	-0.35	-0.19
c109 1-Phenyl-ethanone	-0.06	-0.13	-0.05	-0.05	-0.12	0.04
c110 Trans-2-undecen--1-ol	-0.11	-0.07	-0.21	-0.15	0.00	0.10
c111 Undecanal	-0.01	0.00	-0.03	-0.09	-0.11	-0.10
c112 1-Decanol	0.12	0.22	-0.09	-0.04	-0.01	0.01
c114 Octadecane	0.00	0.13	0.06	-0.06	-0.01	-0.03
c116 Tetradecane	-0.01	-0.09	-0.09	-0.04	0.07	0.07
c117 3-Ethyl-2-methyl-1,3-hexadiene	-0.20	-0.17	-0.11	-0.09	0.02	-0.03
c118 2,4 Nonadienal	-0.05	-0.01	-0.07	-0.15	-0.14	-0.18
c119 Acetic acid	-0.06	-0.09	-0.17	0.00	0.16	0.03
c120 Hentriacontane	-0.18	0.14	-0.12	0.03	0.07	0.00
c121 [(Dodecyloxy) methyl]-oxirane	-0.11	0.08	-0.03	-0.13	-0.02	-0.04
c122 Cyclooctyl alcohol	0.04	-0.20	-0.01	0.21	0.07	0.07
c123 Heneicosane	-0.05	-0.20	-0.08	0.03	0.03	-0.06
c124 2,5-Dimethyl-heptane	-0.01	-0.11	-0.04	0.24	0.16	0.14
c128 Trans,trans-2,4-octadienal	-0.01	-0.03	0.24	0.02	-0.05	-0.17
c129 2-Dodecen-1-ol	0.24	0.20	0.11	-0.11	-0.05	-0.09
c131 1-[2-(2-Methyl-butyl)phenyl] ethanone	-0.11	-0.13	-0.06	0.01	0.08	0.04

Table 6 (Continued).

Effect	Pork Identity	Brown/ Roasted	Fat-Like	Bloody/ Serumy	Metallic	Astringent
c132 (E,E)-2,4-hepta-dienal	0.15	0.13	0.14	0.03	-0.08	-0.11
c133 4-Ethyl-benzalde-hyde	0.00	0.05	0.25	-0.07	-0.14	-0.27
c134 1,1'-Oxybis-heptane	0.02	0.07	0.12	0.00	0.04	-0.06
c135 1-Tetradecanol	-0.09	-0.09	-0.07	-0.02	-0.06	-0.06
c138 1,2-Dimethylpyrro-lidine	0.00	0.03	0.12	-0.15	-0.26	-0.29
c139 2-butyl-2-octenal	-0.05	-0.15	-0.04	-0.01	0.04	0.00
c140 N,N'-bis (3-aminopropyl)-1,3-prop-anediamine	0.02	0.04	-0.02	-0.09	-0.03	0.10
c141 Ethylidene cycloheptane	0.28	0.14	0.09	-0.02	0.03	-0.04
c144 Heptanol	0.22	0.03	0.13	-0.13	-0.02	-0.05
c145 (1-Methylbutyl)-oxirane	0.11	0.16	0.00	-0.17	-0.11	-0.09
c147 4-Oxononanal	0.12	0.04	0.08	-0.08	-0.26	-0.08
c150 Pentadecane	-0.14	0.17	-0.14	0.06	0.17	0.07
c151 Trans-2-tridecenal	0.01	0.21	0.02	-0.06	-0.15	-0.03
c152 Dodecanal	-0.20	0.11	0.01	-0.11	-0.21	-0.16
c154 Octadecanal	0.12	0.08	0.27	-0.12	-0.01	-0.05
c155 2,3,5-Trimethyl pyrazine	0.09	0.15	-0.15	-0.01	0.03	-0.02
c158 (Z)-2-dodecene	0.00	-0.07	-0.11	-0.13	0.07	0.08

Table 6 (Continued).

Effect	Pork Identity	Brown/ Roasted	Fat-Like	Bloody/ Serumy	Metallic	Astringent
c159 (E)-4-dodecene	0.37	-0.07	-0.07	-0.13	0.03	0.07
c160 Nonacosane	0.12	0.04	-0.15	-0.19	-0.08	-0.06
c161 Hexadecanal	-0.05	-0.11	0.10	0.08	0.08	0.06
c162 1,1-Bis(dode-cyloxy)-hexadecane	0.01	0.01	-0.13	-0.07	-0.05	-0.10
c163 Cyclooctane	-0.06	-0.08	-0.15	0.02	0.09	0.05
c164 2-Decanone	0.17	0.24	0.02	-0.10	-0.06	-0.02
c166 Cycloheptane	0.12	0.10	0.10	-0.06	-0.08	-0.11
c167 2-Nonanone	0.11	0.15	-0.03	-0.05	0.01	0.08
c170 3-(1,1-Dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol	0.14	0.23	-0.06	-0.11	-0.02	0.03
c171 Butanoic acid	0.33	0.27	0.08	-0.11	0.02	-0.01
c172 Octenal	0.03	0.12	-0.09	-0.11	-0.08	-0.10
c173 1,3,5,7-Cyclooctate-traene	0.05	-0.07	0.04	0.06	-0.13	0.00
c174 4-(2-Propenyl)-1H-imidazole	-0.02	-0.12	0.22	-0.02	-0.24	-0.12
c175 Chavicol	0.06	0.16	-0.09	-0.12	0.06	-0.01
c177 Formic acid, heptyl ester	-0.07	-0.06	-0.08	-0.05	-0.10	-0.14
c182 6,7-Dodecanedione	-0.04	0.12	-0.15	-0.08	0.07	0.01
c183 Cyclooctanol	0.04	0.26	-0.12	-0.15	0.10	0.01
c184 3-(Methylthio)-propanal	-0.07	0.09	-0.08	-0.02	0.05	0.10

Table 6 (Continued).

Effect	Pork Identity	Brown/ Roasted	Fat-Like	Bloody/ Serumy	Metallic	Astringent
c185 2-Methyl-3-octanone	0.09	0.17	-0.09	-0.06	0.12	0.01
c186 2-Dodecenal	-0.06	-0.09	-0.03	-0.05	0.01	0.07
c188 Dihydro-2(3H)-furanone	-0.07	-0.03	-0.07	-0.10	-0.02	0.08
c189 2-Ethyl-cyclo-butanone	-0.10	-0.12	-0.03	0.03	0.03	0.11
c190 Nitro-L-arginine	-0.02	0.02	-0.15	-0.07	0.04	0.04
c192 3-(1,1-Dimethyl-ethyl)-2,2,4,4-tetramethyl-3-pentanol,	-0.04	-0.08	-0.05	-0.03	0.04	0.06
c194 Decane	0.02	-0.15	0.09	0.10	0.02	0.02
c196 3-Methyl-butanal	0.07	0.07	-0.08	-0.09	0.04	-0.07
c197 (E,E)-2,4-Octadienal	-0.12	-0.16	-0.05	-0.00	-0.02	0.05
c198 Phenyl-oxirane	0.10	-0.05	-0.14	-0.10	-0.08	-0.03
c202 2-Heptanone	-0.20	-0.19	0.19	0.20	0.13	0.16
c203 Formic acid, hexyl ester	-0.06	-0.06	0.04	0.00	0.01	0.04
c205 Delta.-(2)-do-decanol	-0.12	-0.11	-0.11	-0.11	-0.02	-0.03
c207 Undecane	-0.08	-0.06	-0.06	0.04	0.01	-0.02
c208 N,N'-Dimethyl-cyclobutane-1,1-bis(methylamine)	-0.07	0.03	0.10	-0.16	-0.41	-0.24

Table 6 (Continued).

Effect	Pork Identity	Brown/ Roasted	Fat-Like	Bloody/ Serumy	Metallic	Astringent
c210 2-decen-1-ol	-0.11	-0.15	0.10	0.32	0.17	0.16
c212 (1-methylethyl)-benzene	0.15	0.09	-0.00	-0.06	-0.05	-0.05
c214 4-hydroxy-benzoic acid	0.13	0.07	0.03	-0.02	-0.06	0.03
c215 Propyl-propane-dioic acid	-0.07	0.07	-0.04	-0.24	-0.19	-0.14
c217 Cyclooctene	-0.01	-0.03	-0.06	0.00	0.06	0.01
c219 3-(4-Tertiobutyl-phenyl)-propanal	-0.23	-0.16	0.06	0.24	0.13	0.19
c220 Trans-2-undecenal	0.09	0.08	0.08	0.02	0.01	0.04
c221 4-Hydroxymandelic acid	-0.04	0.06	-0.01	0.16	0.12	0.07

[a] Simple correlation coefficients >0.20 are significant (P<0.05).

Table 6 (Continued).

Effect	Sweet	Sour	Salty	Bitter	Umami
c1 2-Octenal	0.06	0.05	-0.02	0.09	0.05
c2 ,4-Nonadienal	0.17	-0.06	0.02	-0.07	-0.30
c3 3-Octanone	-0.12	-0.02	-0.09	0.09	-0.02
c4 5-Pentyl-2(5H)-furanone	0.05	-0.11	0.08	-0.27	-0.07
c6 Acetophenone	-0.07	0.09	0.00	0.01	0.05
c7 Benzaldehyde	-0.06	0.08	-0.03	-0.01	-0.11
c8 3-Ethyl-benzaldehyde	-0.01	0.13	-0.10	-0.03	-0.05
c9 Decanal	-0.35	0.09	-0.12	-0.09	-0.29
c10 Dodecane	-0.07	-0.05	-0.14	0.06	-0.18
c11 2-Pentyl-furan	-0.16	0.11	-0.05	-0.18	-0.16
c12 Hexanoic acid	0.01	0.18	0.12	0.12	-0.09
c13 N-heptanal	0.08	0.16	-0.10	0.18	-0.05
c14 Nonanal	-0.26	0.24	-0.15	0.09	-0.30
c15 Nonenal	-0.10	0.04	-0.09	0.04	-0.15
c16 Octanal	-0.15	0.25	-0.12	0.15	-0.27
c17 Phenol	-0.04	-0.02	0.09	-0.18	0.05
c18 Phenyl acetaldehyde	-0.10	0.09	0.17	0.03	-0.11
c19 Styrene	-0.27	0.06	-0.05	0.05	-0.17
c20 1-Heptanol	-0.10	0.25	-0.12	0.13	-0.17
c21 (E)-2-decenal	0.07	-0.09	-0.02	-0.14	0.10
c22 2,3-Octanedione	-0.05	0.07	-0.06	-0.07	-0.19
c23 2,4-Decadienal	0.16	-0.17	0.06	-0.20	0.28
c24 Hexanal	-0.15	0.17	0.10	0.09	-0.07
c25 3-Isopropyl-piperidine	0.07	-0.09	0.08	-0.13	0.04
c26 Tridecanal	-0.13	0.02	-0.01	-0.02	-0.12

Table 6 (Continued).

Effect	Sweet	Sour	Salty	Bitter	Umami
c27 Undecenal	0.13	-0.08	0.05	-0.17	0.02
c29 1-Octanol	-0.16	0.14	-0.03	-0.00	-0.17
c30 1-Octen-3-ol	-0.16	0.10	-0.07	0.15	-0.11
c32 2-Dococen-1-al	-0.22	0.19	-0.17	-0.00	-0.15
c33 (E)-2-nonenal	0.02	0.11	0.10	-0.09	0.03
c34 1,3-Bis (1,1-di-methylethyl)-benzene	-0.18	0.13	-0.09	0.02	-0.14
c35 benzothiazole	-0.05	-0.15	-0.13	-0.24	-0.12
c37 Dl-limonene	-0.14	0.06	-0.03	-0.18	-0.09
c38 Heptanal	-0.20	0.17	0.04	0.08	-0.16
c40 4-Methyl-phenol	0.08	0.03	0.14	0.07	-0.01
c41 2,5-Dimethyl-pyrazine	-0.20	0.11	0.07	-0.09	0.03
c42 3-Ethyl-2,5-dimethyl-pyrazine	-0.26	0.02	0.16	-0.11	-0.11
c43 Tridecane	0.02	-0.05	-0.09	0.01	-0.06
c44 1-Octen-3-ol	-0.12	0.07	-0.12	-0.07	-0.25
c45 1-Octen-3-one	-0.23	0.11	0.07	-0.11	-0.19
c46 1-Pentanol	-0.07	0.08	0.00	0.01	-0.05
c47 2-Methylene cyclopentanol	-0.10	0.02	0.12	-0.15	0.10
c48 3-Dodecen-1-al	0.04	-0.05	-0.08	-0.06	0.18
c50 Benzene acetaldehyde	-0.27	0.12	-0.05	-0.02	-0.12
c51 1-(1H-pyrrol-2-yl)-ethanone	-0.09	0.16	-0.04	-0.11	-0.08
c52 N-caproic acid, vinyl ester	-0.06	0.18	-0.01	-0.01	-0.11
c54 Nonanoic acid	-0.18	0.07	0.12	-0.15	-0.01
c55 2-Ethyl-5-methyl-pyrazine	-0.21	0.03	0.19	-0.20	-0.07
c57 2-Ethyl-6-methyl-pyrazine	-0.06	0.11	0.07	-0.08	0.08

Table 6 (Continued).

Effect	Sweet	Sour	Salty	Bitter	Umami
c58 methyl-pyrazine	-0.14	-0.02	0.21	-0.18	-0.10
c60 1-Hexanol	0.01	0.05	0.03	0.12	-0.20
c61 1-Pyrrolidine carboxaldehyde	0.19	-0.19	-0.07	0.04	0.22
c63 (E)-2-octen-1-ol	-0.09	0.01	-0.03	-0.21	-0.15
c64 2,4 Decadienal	0.04	-0.09	-0.12	-0.05	0.02
c65 2,4 Heptadienal	0.11	-0.09	0.12	0.14	-0.02
c66 Octanoic acid	-0.10	-0.04	-0.03	0.11	-0.07
c67 Pentanal	0.10	-0.07	0.09	0.10	-0.02
c69 2-Ethyl-3,5-dimethyl-pyrazine	-0.02	0.05	0.05	0.03	-0.11
c72 2-Acetyl thiazole	-0.08	0.22	-0.00	0.07	-0.13
c73 2-Butylfuran	0.03	0.00	0.08	0.16	-0.10
c74 2-Heptanone	-0.18	0.20	-0.11	0.07	-0.23
c75 (E)-2-heptenal	0.06	0.02	0.10	0.14	-0.05
c77 1-Methyl-4-(1-methylethyl)-benzene	0.13	-0.05	0.12	-0.03	0.07
c79 2-Ethyl-1-hexanol	-0.11	0.21	-0.11	0.19	-0.03
c80 (E)-2-hexenal	-0.02	0.17	-0.14	0.28	-0.11
c82 (E)-2-octenal	-0.15	0.06	-0.02	-0.08	-0.07
c83 1-Propoxy-2-propanol	-0.12	0.18	-0.21	0.19	0.04
c84 2,5-Octanedione	-0.21	0.10	0.01	0.10	-0.11
c86 Ethyl-benzene	-0.11	0.16	-0.21	0.17	0.04
c87 Hexadecane	-0.16	0.06	-0.19	0.16	0.05
c90 Methyl-pyrazine	-0.10	-0.01	-0.13	-0.06	-0.09
c91 6-Methyl-2-heptanone	-0.03	0.04	-0.16	-0.03	-0.19
c92 1-(4,5-Dihydro-2-thiazolyl)-ethanone	0.01	0.06	0.05	0.04	-0.05

Table 6 (Continued).

Effect	Sweet	Sour	Salty	Bitter	Umami
c94 Octane	0.14	-0.10	0.17	-0.05	0.09
c97 1,2-Benzisothiazole	-0.02	-0.11	0.10	-0.02	0.13
c98 2,3-Dimethylbenzaldehyde	0.15	-0.15	0.23	-0.05	0.54
c99 4-Octen-3-one	-0.03	-0.05	0.09	0.05	0.20
c100 Benzophenone	-0.00	0.04	0.02	0.08	0.19
c101 Heptanoic acid	0.06	-0.08	0.10	-0.17	-0.07
c102 Heptenal	0.04	-0.21	0.03	0.01	0.15
c103 Nonadecane	-0.05	-0.04	0.07	-0.12	-0.05
c105 Tetradecanal	-0.06	-0.05	-0.12	-0.13	-0.06
c109 1-Phenyl-ethanone	-0.11	0.10	-0.10	0.01	-0.13
c110 Trans-2-undecen-1-ol	-0.19	0.08	-0.09	0.03	-0.14
c111 Undecanal	-0.01	-0.07	-0.10	-0.22	0.03
c112 1-Decanol	-0.02	-0.01	0.20	-0.01	-0.09
c114 Octadecane	0.07	-0.09	0.08	-0.15	0.11
c116 Tetradecane	0.04	0.03	-0.13	0.03	-0.09
c117 3-Ethyl-2-methyl-1,3-hexadiene	-0.08	-0.08	-0.07	-0.10	-0.13
c118 2,4 Nonadienal	-0.07	-0.21	0.08	-0.26	-0.02
c119 Acetic acid	-0.13	0.09	0.05	-0.02	-0.04
c120 Hentriacontane	-0.06	0.04	0.02	-0.12	-0.13
c121 [(Dodecyloxy)methyl]-oxirane	-0.03	-0.07	-0.06	-0.21	-0.12
c122 Cyclooctyl alcohol	-0.01	0.05	-0.17	0.30	0.05
c123 Heneicosane	-0.07	-0.11	-0.26	0.09	-0.04
c124 2,5-Dimethyl-heptane	-0.01	0.11	-0.07	0.21	-0.07
c128 Trans, trans-2,4-octadienal	0.06	-0.06	0.15	0.13	-0.00
c129 2-Dodecen-1-ol	0.08	-0.07	0.19	0.10	0.20

Table 6 (Continued).

Effect	Sweet	Sour	Salty	Bitter	Umami
c131 1-[2-(2-Methylbutyl)phenyl] ethanone	0.06	-0.03	0.06	0.04	-0.15
c132 (E,E)-2,4-heptadienal	0.18	-0.07	0.10	-0.12	0.01
c133 4-Ethyl-benzaldehyde	0.06	-0.06	0.17	0.06	0.06
c134 1,1'-Oxybis-heptane	-0.01	-0.03	0.17	0.14	-0.11
c135 1-Tetradecanol	0.02	0.02	-0.11	0.10	-0.11
c138 1,2-Dimethylpyrrolidine	0.07	-0.03	0.05	-0.00	0.08
c139 2-butyl-2-octenal	0.04	0.08	-0.12	0.03	-0.12
c140 N,N'-bis (3-amino-propyl)-1,3-propanediamine	-0.13	0.05	0.17	-0.02	-0.06
c141 Ethylidene cycloheptane	-0.04	0.01	0.11	0.18	0.01
c144 Heptanol	0.01	-0.04	0.18	0.06	0.07
c145 (1-Methylbutyl)-oxirane	0.01	-0.09	0.14	-0.03	0.00
c147 4-Oxononanal	0.05	-0.09	-0.12	-0.09	0.18
c150 Pentadecane	-0.12	0.06	-0.10	-0.04	-0.16
c151 Trans-2-tridecenal	-0.11	-0.08	-0.09	-0.14	-0.05
c152 Dodecanal	-0.10	-0.14	-0.08	-0.22	-0.07
c154 Octadecanal	0.10	-0.08	0.12	-0.03	0.44
c155 2,3,5-Trimethyl pyrazine	-0.16	0.07	-0.03	0.16	-0.04
c158 (Z)-2-dodecene	-0.01	-0.02	-0.11	0.06	-0.11
c159 (E)-4-dodecene	0.02	0.00	-0.05	0.03	-0.08
c160 Nonacosane	0.10	-0.04	-0.12	-0.02	-0.04
c161 Hexadecanal	0.05	0.11	0.01	0.14	0.11
c162 1,1-Bis(dodecyloxy)-hexadecane	-0.10	-0.03	-0.12	-0.09	-0.11
c163 Cyclooctane	-0.13	0.12	-0.08	-0.02	-0.07

Table 6 (Continued).

Effect	Sweet	Sour	Salty	Bitter	Umami
c164 2-Decanone	-0.05	-0.00	0.24	0.03	-0.13
c166 Cycloheptane	0.09	-0.06	0.20	0.00	0.08
c167 2-Nonanone	-0.12	0.04	0.22	0.01	-0.11
c170 3-(1,1-Dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol	-0.04	-0.04	0.26	-0.05	-0.07
c171 Butanoic acid	0.10	-0.02	0.21	0.03	0.10
c172 Octenal	-0.03	-0.07	0.23	-0.11	-0.04
c173 1,3,5,7-Cyclooctatetraene	0.07	-0.00	-0.07	0.08	0.10
c174 4-(2-Propenyl)-1H-imidazole	0.12	-0.06	-0.06	-0.08	0.18
c175 Chavicol	-0.09	-0.16	0.02	0.04	-0.01
c177 Formic acid, heptyl ester	0.01	-0.06	0.07	-0.10	0.01
c182 6,7-Dodecanedione	-0.12	-0.12	-0.03	0.10	-0.11
c183 Cyclooctanol	-0.15	0.05	0.01	-0.01	0.07
c184 3-(Methylthio)-propanal	-0.06	0.08	0.01	0.04	-0.13
c185 2-Methyl-3-octanone	-0.13	0.12	0.08	-0.04	0.01
c186 2-Dodecenal	-0.00	0.02	-0.02	-0.03	0.07
c188 Dihydro-2(3H)-furanone	-0.03	0.03	-0.01	-0.07	0.01
c189 2-Ethyl-cyclobutanone	0.00	0.08	0.02	-0.01	0.04
c190 Nitro-L-arginine	0.02	0.04	0.03	-0.01	0.15
c192 3-(1,1-Dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol,	0.14	0.18	-0.09	0.08	-0.10
c194 Decane	0.17	0.04	-0.12	0.19	0.08
c196 3-Methyl-butanal	0.13	-0.07	0.17	-0.07	0.30

Table 6 (Continued).

Effect	Sweet	Sour	Salty	Bitter	Umami
c197 2(E,E)-2,4-Octadienal	-0.08	0.03	0.06	0.01	-0.08
c198 Phenyl-oxirane	0.14	-0.12	-0.03	-0.06	0.02
c202 2-Heptanone	0.09	0.05	-0.12	0.04	-0.02
c203 Formic acid, hexyl ester	-0.03	0.01	0.03	-0.08	-0.02
c205 Delta.-(2)-dodecanol	0.10	-0.14	0.09	-0.12	-0.06
c207 Undecane	0.07	-0.06	-0.02	0.01	-0.04
c208 N,N'-Dimethyl-cyclobutane-1,1-bis-(methylamine)	0.02	-0.23	-0.06	-0.15	0.09
c210 2-decen-1-ol	0.22	0.04	0.18	0.04	0.02
c212 (1-methylethyl)-benzene	0.07	-0.09	0.10	0.01	0.10
c214 4-hydroxy-benzoic acid	0.16	-0.12	0.10	-0.17	0.15
c215 Propyl-propanedioic acid	0.04	-0.19	-0.10	-0.13	-0.08
c217 Cyclooctene	-0.09	0.12	-0.11	0.05	-0.08
c219 3-(4-Tertiobutylphenyl)-propanal	-0.07	0.08	-0.12	0.08	-0.06
c220 Trans-2-undecenal	0.08	-0.11	0.08	-0.12	0.06
c221 4-Hydroxymandelic acid	-0.11	0.05	0.08	0.12	-0.07

[a] Simple correlation coefficients >0.203 are significant (P<0.05)

Table 7. Simple correlation coefficients[a] between trained descriptive sensory attributes and volatile compound categories.

Effect	Pork Identity	Brown/ Roasted	Fat-Like	Bloody/ Serumy	Metallic	Astringent
Sulfur-containing	-0.16	0.09	-0.07	-0.04	-0.12	0.00
Nitrogen-containing	0.16	0.33	-0.23	-0.25	-0.12	-0.13
Aldehydes	-0.15	-0.10	-0.15	0.04	0.17	0.12
Alcohols	-0.22	-0.15	-0.16	-0.00	0.11	0.10
Ketones	-0.21	-0.02	-0.17	-0.01	0.11	0.11
Acids	-0.12	-0.12	-0.12	0.03	0.13	0.10
Alkanes	-0.08	-0.09	-0.17	-0.09	0.10	0.06
Alkenes	-0.13	-0.06	-0.16	-0.09	0.05	-0.00
Furans	-0.17	-0.06	-0.19	-0.02	0.11	0.09
Pyrazines	0.20	0.32	-0.25	0.23	-0.07	-0.10
Benzenes	-0.18	-0.06	-0.25	-0.06	-0.01	0.04

[a] Simple correlation coefficients >0.20 are significant ($P<0.05$).

Table 7 (Continued).

Effect	Sweet	Sour	Salty	Bitter	Umami
Sulfur-containing	-0.10	-0.02	-0.04	-0.13	-0.14
Nitrogen-containing	-0.26	0.05	0.12	-0.16	-0.07
Aldehydes	-0.19	0.24	-0.01	0.12	-0.20
Alcohols	-0.22	0.18	-0.11	0.04	-0.29
Ketones	-0.24	0.14	-0.06	-0.01	-0.30
Acids	-0.08	0.21	0.06	0.02	-0.13
Alkanes	-0.09	-0.02	-0.12	0.07	-0.20
Alkenes	-0.19	0.03	-0.10	-0.09	-0.17
Furans	-0.16	0.11	-0.05	-0.18	-0.16
Pyrazines	-0.26	0.07	0.14	-0.12	-0.07
Benzenes	-0.10	0.10	-0.03	-0.01	-0.14

[a] Simple correlation coefficients >0.203 are significant (P<0.05)

Table 8. Stepwise linear regression for prediction of pork identity flavor aromatics as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
Intercept		5.66		
1	c171 Butanoic acid	0.05	0.11	0.11
2	c23 2,4-Decadienal	0.01	0.10	0.20
3	c141 Ethylidene cycloheptane	0.11	0.08	0.28
4	c208 N,N'-Dimethylcyclobutane-1,1-bis(methylamine)	-0.29	0.07	0.35
5	c20 1-Heptanol	-0.008	0.06	0.41
6	c92 1-(4,5-Dihydro-2-thiazolyl)-ethanone	0.28	0.05	0.45
7	c207 Undecane	-0.15	0.04	0.49
8	c57 2-Ethyl-6-methyl-pyrazine	0.17	0.03	0.52
9	c52 N-caproic acid, vinyl ester	-0.003	0.04	0.56
10	c6 Acetophenone	0.07	0.02	0.58
11	c38 Heptanal	-0.001	0.03	0.61
12	c29 1-Octanol	0.005	0.02	0.63
13	c120 Hentriacontane	0.12	0.02	0.65
14	c188 Dihydro-2(3H)-furanone	-0.02	0.02	0.67
15	c4 5-Pentyl-2(5H)-furanone	0.06	0.02	0.69
16	c98 2,3-Dimethylbenzaldehyde	0.20	0.02	0.71
17	c114 Octadecane	-0.19	0.03	0.74
18	c145 (1-Methylbutyl)-oxirane	0.08	0.02	0.76
19	c152 Dodecanal	-0.02	0.02	0.78
21	c219 3-(4-Tertiobutylphenyl)-propanal	-0.02	0.01	0.79
23	c110 Trans-2-undecen-1-ol	-0.04	0.01	0.80
24	c185 2-Methyl-3-octanone	0.005	0.01	0.81
25	c162 1,1-Bis(dodecyloxy)-hexadecane	0.18	0.01	0.82
26	c7 Benzaldehyde	-0.008	0.01	0.83
27	c166 Cycloheptane	0.02	0.01	0.84
28	c210 2-decen-1-ol	-0.04	0.01	0.85
29	c215 Propyl-propanedioic acid	-0.08	0.01	0.86
30	c94 Octane	0.05	0.01	0.86
31	c32 2-Dococen-1-al	-0.01	0.01	0.87
32	c220 Trans-2-undecenal	0.05	0.01	0.88
33	c91 6-Methyl-2-heptanone	-0.04	0.01	0.88
34	c13 N-heptanal	0.001	0.00	0.89
35	c47 2-Methylene cyclopentanol	-0.04	0.00	0.89
37	c80 (E)-2-hexenal	-0.02	0.01	0.90
38	c121 [(Dodecyloxy)methyl]-oxirane	-0.09	0.01	0.90

Table 8 (Continued).

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
39	c82 (E)-2-octenal	0.003	0.00	0.90
42	c8 3-Ethyl-benzaldehyde	0.02	0.01	0.91
43	c27 Undecenal	-0.006	0.00	0.91
44	c25 3-Isopropyl-piperidine	0.09	0.00	0.91
45	c65 2,4 Heptadienal	0.02	0.00	0.92
46	c75 ((E)-2-heptenal	-0.04	0.00	0.92
49	c3 3-Octanone	-0.003	0.01	0.92
50	c105 Tetradecanal	-0.01	0.00	0.93

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 9. Stepwise linear regression for prediction of fat-like flavor aromatics as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
Intercept		0.56		
1	c98 2,3-Dimethylbenzaldehyde	0.70	0.14	0.14
2	c133 4-Ethyl-benzaldehyde	0.09	0.07	0.21
3	c2 2,4-Nonadienal	0.03	0.04	0.25
4	c202 2-Heptanone	0.05	0.05	0.30
5	c14 Nonanal	-0.0008	0.05	0.35
6	c110 Trans-2-undecen-1-ol	-0.09	0.04	0.38
7	c160 Nonacosane	-0.54	0.02	0.41
8	c43 Tridecane	0.04	0.02	0.43
9	c10 Dodecane	-0.009	0.05	0.48
10	c147 4-oxononanal	-0.37	0.02	0.50
11	c121 [(Dodecyloxy)methyl]-oxirane	0.12	0.01	0.51
12	c111 undecanal	-0.09	0.02	0.53
14	c183 Cyclooctanol	-0.06	0.02	0.54
15	c37 Dl-limonene	0.03	0.02	0.56
16	c11 2-Pentyl-furan	-0.003	0.02	0.59
17	c21 (E)-2-decenal	0.01	0.02	0.60
18	c9 Decanal	-0.02	0.02	0.62
19	c166 Cycloheptane	0.03	0.01	0.63
20	c161 Hexadecanal	0.23	0.01	0.64
21	c120 Hentriacontane	-0.14	0.01	0.66
22	c185 2-Methyl-3-octanone	0.01	0.01	0.67
23	c141 Ethylidene cycloheptane	0.05	0.01	0.68
24	c184 propanal, 3-(methylthio)-	0.10	0.01	0.69
26	c50 Benzene acetaldehyde	-0.06	0.02	0.71
27	c35 Benzothiazole	-0.04	0.02	0.72
29	c139 2-butyl-2-octenal	-0.16	0.01	0.73
31	c196 3-Methyl-butanal	-0.04	0.01	0.74
32	c101 Heptanoic acid	-0.05	0.01	0.75
33	c208 N,N'-Dimethylcyclobutane-1,1-bis(methylamine)	0.18	0.01	0.76
34	c147 4-Oxononanal	-0.43	0.02	0.78
35	c29 1-Octanol	-0.005	0.01	0.79
36	c207 Undecane	0.10	0.01	0.80

Table 9 (Continued).

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
37	c65 2,4 Heptadienal	0.05	0.01	0.80
40	c73 2-Butylfuran	-0.12	0.02	0.82
42	c210 2-decen-1-ol	0.04	0.01	0.82
43	c128 Trans, trans-2,4-octadienal	0.10	0.01	0.83

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 10. Stepwise linear regression for prediction of brown/roasted flavor aromatics as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
Intercept		0.79		
1	c42 3-Ethyl-2,5-dimethyl-pyrazine	0.07	0.09	0.09
2	c91 6-Methyl-2-heptanone	-0.24	0.10	0.19
3	c99 4-Octen-3-one	0.31	0.05	0.24
4	c18 Phenyl acetaldehyde	0.06	0.06	0.30
5	c151 Trans-2-tridecenal	0.07	0.06	0.36
6	c183 Cyclooctanol	0.10	0.06	0.42
7	c14 Nonanal	-0.001	0.07	0.48
8	c129 2-Dodecen-1-ol	0.22	0.04	0.52
9	c98 2,3-Dimethylbenzaldehyde	0.44	0.04	0.56
10	c4 5-Pentyl-2(5H)-furanone	0.11	0.03	0.63
11	c51 1-(1H-pyrrol-2-yl)-ethanone	0.12	0.04	0.63
12	c119 Acetic acid	0.07	0.03	0.66
13	c138 1,2-Dimethylpyrrolidine	0.16	0.03	0.69
14	c8 3-Ethyl-benzaldehyde	-0.05	0.02	0.71
15	c192 3-(1,1-Dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol,	-0.03	0.02	0.73
16	c203 Formic acid, hexyl ester	-0.10	0.02	0.75
17	c220 Trans-2-undecenal	0.11	0.01	0.76
18	c103 Nonadecane	0.12	0.01	0.78
19	c152 Dodecanal	0.01	0.01	0.79
20	c44 1-Octen-3-ol	-0.002	0.01	0.80
21	c83 1-Propoxy-2-propanol	0.05	0.01	0.81
22	c161 Hexadecanal	-0.02	0.01	0.81
23	c185 2-Methyl-3-octanone	-0.009	0.01	0.82
24	c74 2-Heptanone	-0.02	0.01	0.83
25	c166 Cycloheptane	-0.02	0.01	0.83
26	c13 N-heptanal	0.001	0.01	0.84
28	c189 2-Ethyl-cyclobutanone	-0.01	0.01	0.84
29	c186 2-Dodecenal	0.02	0.01	0.85
30	c162 1,1-Bis(dodecyloxy)-hexadecane	-0.20	0.01	0.86
31	c163 Cyclooctane	0.007	0.01	0.86
32	c117 3-Ethyl-2-methyl-1,3-hexadiene	0.01	0.00	0.87
33	c123 Heneicosane	-0.02	0.01	0.87
34	c141 Ethylidene cycloheptane	-0.06	0.00	0.88
35	c26 Tridecanal	0.07	0.01	0.89
36	c1 2-Octenal	0.004	0.01	0.89
38	c139 2-butyl-2-octenal	0.02	0.01	0.90
39	c207 Undecane	-0.08	0.01	0.90

Table 10 (Continued).

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
40	c221 4-Hydroxymandelic acid	-0.03	0.01	0.91
41	c84 2,5-Octanedione	-0.005	0.00	0.91
42	c133 4-Ethyl-benzaldehyde	-0.04	0.00	0.91

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 11. Stepwise linear regression for prediction of bloody/serumy flavor aromatics as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
Intercept		1.16		
1	c210 2-decen-1-ol	0.22	0.10	0.10
2	c219 3-(4-tertiobutylphenyl)-propanal	0.06	0.06	0.16
3	c124 2,5-Dimethyl-heptane	0.11	0.06	0.23
4	c215 Propyl-propanedioic acid	-0.30	0.05	0.27
5	c72 2-Acetyl thiazole	0.13	0.04	0.31
6	c58 Trimethyl-pyrazine	-0.03	0.05	0.36
7	c160 Nonacosane	-0.94	0.03	0.39
8	c145 (1-Methylbutyl)-oxirane	-0.14	0.03	0.42
9	c138 1,2-dimethylpyrrolidine	-0.18	0.03	0.45
10	c20 1-Heptanol	0.01	0.03	0.48
11	c82 (E)-2-octenal	-0.01	0.03	0.51
13	c205 Delta.-(2)-dodecanol	-0.06	0.02	0.53
14	c112 1-Decanol	0.27	0.02	0.54
15	c170 3-(1,1-Dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol	-0.16	0.05	0.59
17	c117 3-Ethyl-2-methyl-1,3-hexadiene	-0.02	0.02	0.60
18	c155 2,3,5-Trimethyl pyrazine	-0.04	0.02	0.62
19	c69 2-Ethyl-3,5-dimethyl-pyrazine	-0.24	0.02	0.64
20	c6 Acetophenone	-0.11	0.02	0.66
21	c154 Octadecanal	-0.09	0.02	0.68
22	c175 Chavicol	-0.29	0.02	0.69
23	c208 N,N'-dimethylcyclobutane-1,1-bis(methylamine)	-0.22	0.02	0.71
24	c116 Tetradecane	0.03	0.02	0.72
25	c43 Tridecane	-0.05	0.02	0.73
26	c114 Octadecane	-0.25	0.01	0.75
28	c110 Trans-2-undecen-1-ol	-0.07	0.01	0.75
29	c47 2-Methylene cyclopentanol	-0.06	0.01	0.76
30	c51 1-(1H-pyrrol-2-yl)-ethanone 0.08	0.01	0.77	
31	c30 1-Octen-3-ol	0.003	0.01	0.78
32	c162 1,1-Bis(dodecyloxy)-hexadecane	0.37	0.01	0.79
33	c41 2,5-Dimethyl-pyrazine	-0.09	0.01	0.80
34	c23 2,4-Decadienal	-0.008	0.01	0.81
36	c103 Nonadecane	-0.12	0.01	0.82
37	c86 Ethyl-benzene	-0.10	0.01	0.82
38	c140 N,N'-bis (3-aminopropyl)-1,3-propanediamine	0.26	0.01	0.83
39	c144 Heptanol	-0.07	0.01	0.85

Table 11 (Continued).

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
42	c66 Octanoic acid	0.02	0.01	0.85
43	c152 Dodecanal	-0.01	0.01	0.86
44	c77 1-Methyl-4-(1-methylethyl) -benzene	-0.05	0.01	0.87
45	c99 4-Octen-3-one	0.19	0.01	0.88
46	c42 3-Ethyl-2,5-dimethyl- pyrazine	-0.06	0.01	0.89
47	c46 1-Pentanol	0.008	0.01	0.89
48	c139 2-butyl-2-octenal	-0.21	0.01	0.90
49	c21 (E)-2-decenal	0.01	0.00	0.90
51	c141 Ethylidene cycloheptane	0.11	0.01	0.91
52	c91 6-Methyl-2-heptanone	0.12	0.01	0.91
53	c19 Styrene	0.04	0.01	0.92
54	c64 2,4-Decadienal	-0.03	0.01	0.92
55	c7 Benzaldehyde	0.001	0.01	0.93
56	c82 (E)-2-octenal	-0.005	0.00	0.93
57	c203 Formic acid, hexyl ester	-0.08	0.00	0.94
58	c1 2-Octenal	-0.004	0.00	0.94

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 12. Stepwise linear regression for prediction of metallic flavor aromatics as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
Intercept		2.07		
1	c208 N,N'-dimethylcyclobutane-1,1-bis(methylamine)	-0.32	0.17	0.17
2	c138 1,2-dimethylpyrrolidine	-0.14	0.07	0.24
3	c20 1-Heptanol	0.008	0.07	0.31
4	c102 Heptenal	-0.06	0.03	0.34
5	c42 3-Ethyl-2,5-dimethyl-pyrazine	-0.02	0.03	0.38
6	c215 Propyl-propanedioic acid	-0.12	0.03	0.41
7	c118 2,4 Nonadienal	-0.07	0.04	0.45
8	c23 2,4-Decadienal	-0.006	0.03	0.48
9	c197 (E,E)-2,4-Octadienal	-0.06	0.02	0.50
10	c74 2-Heptanone	0.01	0.03	0.53
11	c37 Dl-limonene	0.02	0.02	0.55
12	c139 2-butyl-2-octenal	0.13	0.02	0.57
13	c1 2-Octenal	-0.003	0.02	0.59
14	c84 2,5-Octanedione	-0.004	0.01	0.60
15	c24 Hexanal	0.0002	0.02	0.62
16	c90 Methyl-pyrazine	0.03	0.02	0.64
17	c109 1-Phenyl-ethanone	0.02	0.02	0.66
19	c141 Ethylidene cycloheptane	0.04	0.01	0.67
20	c99 4-Octen-3-one	0.09	0.01	0.68
21	c40 4-Methyl-phenol	-0.02	0.01	0.69
22	c32 2-Dococen-1-al	0.02	0.01	0.70
23	c35 Benzothiazole	-0.03	0.01	0.71
26	c190 Nitro-L-arginine	-0.10	0.01	0.72
28	c25 3-Isopropyl-piperidine	-0.11	0.01	0.72
29	c210 2-decen-1-ol	0.04	0.01	0.74
30	c14 Nonanal	0.0006	0.01	0.75
32	c4 5-Pentyl-2(5H)-furanone	-0.05	0.01	0.76
33	c221 4-hydroxymandelic acid	0.02	0.01	0.77

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 13. Stepwise linear regression for prediction of astringent feeling factors as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
Intercept		1.79		
1	c138 1,2-dimethylpyrrolidine	-0.14	0.08	0.08
2	c20 1-Heptanol	0.009	0.11	0.19
3	c208 N,N'-dimethylcyclobutane-1,1-bis(methylamine)	-0.17	0.05	0.24
4	c109 1-Phenyl-ethanone	0.03	0.04	0.28
5	c42 3-Ethyl-2,5-dimethyl-pyrazine	-0.03	0.05	0.33
6	c118 2,4 Nonadienal	-0.07	0.04	0.37
7	c215 Propyl-propanedioic acid	-0.10	0.03	0.40
8	c23 2,4-Decadienal	-0.006	0.03	0.43
10	c74 2-Heptanone	0.01	0.05	0.47
11	c101 Heptanoic acid	-0.06	0.04	0.51
12	c61 1-Pyrrolidine carboxaldehyde	-0.12	0.02	0.53
13	c147 4-Oxononanal	0.29	0.02	0.55
14	c105 Tetradecanal	-0.02	0.02	0.58
15	c72 2-Acetyl thiazole	0.04	0.02	0.59
16	c52 N-caproic acid, vinyl ester	0.007	0.01	0.60
17	c217 Cyclooctene	-0.01	0.01	0.62
18	c99 4-Octen-3-one	0.09	0.01	0.63
19	c32 2-Dococen-1-al	0.02	0.01	0.64
20	c90 Methyl-pyrazine	-0.04	0.03	0.67
21	c38 Heptanal	-0.0006	0.01	0.68
22	c184 3-(Methylthio)-propanal	0.07	0.02	0.70
23	c192 3-(1,1-Dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol,	0.02	0.02	0.71
24	c112 1-Decanol	0.13	0.01	0.73
25	c110 trans-2-undecen-1-ol	0.03	0.01	0.74
26	c131 1-[2-(2-Methylbutyl)phenyl] ethanone	0.02	0.01	0.75
27	c69 2-Ethyl-3,5-dimethyl-pyrazine	-0.14	0.03	0.78
28	c162 1,1-Bis(dodecyloxy)-hexadecane	-0.57	0.02	0.80
30	c91 6-Methyl-2-heptanone	0.05	0.01	0.81
31	c47 2-Methylene cyclopentanol	0.04	0.01	0.82
32	c160 Nonacosane	-0.22	0.01	0.83
33	c10 Dodecane	0.002	0.01	0.84
34	c167 2-Nonanone	-0.08	0.01	0.85
35	c220 trans-2-undecenal	0.04	0.01	0.86
36	c27 Undecenal	0.006	0.01	0.87

Table 13 (Continued).

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
37	c175 Chavicol	-0.10	0.01	0.87

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 14. Stepwise linear regression for prediction of sour basic taste as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
Intercept		1.80		
1	c20 1-Heptanol	0.01	0.06	0.06
2	c72 2-Acetyl thiazole	0.10	0.05	0.12
3	c32 2-Dococecen-1-al	0.03	0.05	0.16
4	c118 2,4 Nonadienal	-0.11	0.05	0.21
5	c208 N,N'-dimethylcyclobutane-1,1-bis(methylamine)	-0.22	0.04	0.25
6	c192 3-(1,1-Dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol,-	0.03	0.04	0.29
7	c117 3-Ethyl-2-methyl-1,3-hexadiene	-0.01	0.03	0.31
8	c90 Methyl-pyrazine	-0.06	0.03	0.35
9	c83 1-Propoxy-2-propanol	0.08	0.03	0.38
10	c51 1-(1H-pyrrol-2-yl)-ethanone	0.08	0.03	0.41
11	c110 Trans-2-undecen-1-ol	0.07	0.02	0.44
12	c185 2-Methyl-3-octanone	0.009	0.02	0.46
13	c161 Hexadecanal	0.27	0.02	0.48
15	c4 5-Pentyl-2(5H)-furanone	-0.07	0.02	0.51
16	c8 3-Ethyl-benzaldehyde	0.05	0.03	0.55
18	c103 Nonadecane	-0.10	0.02	0.55
19	c135 1-Tetradecanol	-0.21	0.02	0.57
21	c215 Propyl-propanedioic acid	-0.13	0.02	0.58
22	c74 2-Heptanone	0.02	0.02	0.60
23	c84 2,5-Octanedione	-0.009	0.02	0.62
25	c33 (E)-2-nonenal	-0.02	0.02	0.63
26	c118 2,4 Nonadienal	-0.08	0.02	0.65
27	c61 1-Pyrrolidine carboxaldehyde	-0.19	0.02	0.67
28	c102 Heptenal	-0.06	0.01	0.68
29	c175 Chavicol	-0.18	0.01	0.70
30	c184 3-(Methylthio)-propanal	0.13	0.01	0.71
31	c92 1-(4,5-Dihydro-2-thiazolyl)-ethanone	0.23	0.01	0.72
32	c99 4-Octen-3-one	0.14	0.01	0.74
33	c87 Hexadecane	0.09	0.01	0.75
34	c122 Cyclooctyl alcohol	-0.07	0.01	0.77
35	c214 4-hydroxy-benzoic acid	-0.16	0.01	0.78
36	c207 Undecane	0.10	0.01	-0.79
37	c164 2-Decanone	0.12	0.01	0.80
38	c18 Phenyl acetaldehyde	-0.04	0.02	0.82
39	c198 Phenyl-oxirane	-0.08	0.01	0.83

Table 14 (Continued).

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
41	c43 Tridecane	-0.02	0.01	0.83
42	c116 Tetradecane	0.03	0.02	0.85
43	c52 N-caproic acid, vinyl ester	0.006	0.01	0.86
44	c212 (1-methylethyl)-benzene	-0.10	0.01	0.87
45	c133 4-Ethyl-benzaldehyde	0.03	0.01	0.87
46	c173 1,3,5,7-Cyclooctatetraene	0.09	0.01	0.88
47	c22 2,3-Octanedione	-0.003	0.01	0.89
49	c203 Formic acid, hexyl ester	0.06	0.01	0.89
50	c221 4-hydroxymandelic acid	0.03	0.01	0.90
51	c27 Undecenal	-0.009	0.01	0.91
52	c155 2,3,5-Trimethyl pyrazine	0.01	0.00	0.91
53	c177 Formic acid, heptyl ester	0.06	0.01	0.92
55	c15 Nonenal	-0.02	0.01	0.92
56	c185 2-Methyl-3-octanone	-0.004	0.00	0.92
58	c6 Acetophenone	0.05	0.01	0.92
61	c150 Pentadecane	0.08	0.00	0.92
62	c19 Styrene	0.03	0.00	0.93
63	c75 (E)-2-heptenal	0.005	0.01	0.93
67	c197 (E,E)-2,4-Octadienal	0.07	0.01	0.93
68	c9 Decanal	-0.02	0.00	0.94
70	c27 Undecenal	-0.008	0.00	0.94
71	c159 (E)-4-dodecene	-0.08	0.00	0.94
72	c45 1-Octen-3-one	0.01	0.00	0.95
73	c55 2-Ethyl-5-methyl-pyrazine	-0.05	0.00	0.95
74	c44 1-Octen-3-ol	-0.0009	0.00	0.95
75	c40 4-Methyl-phenol	-0.02	0.00	0.96

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 15. Stepwise linear regression for prediction of salty basic taste as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
Intercept		1.21		
1	c123 Heneicosane	-0.21	0.07	0.07
2	c170 3-(1,1-Dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol	0.03	0.06	0.13
3	c98 2,3-Dimethylbenzaldehyde	0.21	0.05	0.18
4	c86 Ethyl-benzene	-0.08	0.04	0.22
5	c18 Phenyl acetaldehyde	0.02	0.05	0.27
6	c32 2-Dococen-1-al	-0.02	0.05	0.32
7	c129 2-Dodecen-1-ol	0.09	0.03	0.35
8	c94 Octane	0.04	0.04	0.39
9	c210 2-decen-1-ol	0.05	0.04	0.42
10	c55 2-Ethyl-5-methyl-pyrazine	0.04	0.03	0.45
12	c33 (E)-2-nonenal	0.008	0.02	0.47
13	c91 6-Methyl-2-heptanone	-0.06	0.04	0.50
14	c51 1-(1H-pyrrol-2-yl)-ethanone	-0.04	0.02	0.53
15	c74 2-Heptanone	-0.009	0.02	0.55
16	c154 Octadecanal	-0.07	0.02	0.57
17	c119 Acetic acid	-0.02	0.01	0.58
18	c118 2,4 Nonadienal	0.04	0.01	0.59
19	c196 3-Methyl-butanal	0.03	0.02	0.61
21	c217 Cyclooctene	-0.02	0.02	0.62
22	c192 3-(1,1-Dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol,	-0.01	0.02	0.64
23	c170 3-(1,1-Dimethylethyl)-2,2,4,4-tetramethyl-3-pentanol	0.02	0.01	0.65
24	c19 Styrene	0.02	0.01	0.66
25	c20 1-Heptanol	-0.004	0.02	0.68
26	c65 2,4 Heptadienal	0.02	0.02	0.70
27	c73 2-Butylfuran	-0.07	0.03	0.72
28	c48 3-Dodecen-1-al	-0.005	0.02	0.74
29	c45 1-Octen-3-one	0.01	0.02	0.76
32	c21 (E)-2-decenal	0.004	0.01	0.77
34	c212 (1-methylethyl)-benzene	0.13	0.02	0.78
36	c185 2-Methyl-3-octanone	0.004	0.02	0.79
37	c140 N,N'-bis (3-aminopropyl)-1,3-propanediamine	0.11	0.01	0.80
39	c112 1-Decanol	0.12	0.01	0.80
40	c188 Dihydro-2(3H)-furanone	0.007	0.01	0.81
41	c147 4-Oxononanal	-0.15	0.01	0.82

Table 15 (Continued).

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
42	c40 4-Methyl-phenol	0.01	0.01	0.83
44	c69 2-Ethyl-3,5-dimethyl-pyrazine	-0.05	0.01	0.83
45	c52 N-caproic acid, vinyl ester	0.002	0.01	0.84
46	c99 4-Octen-3-one	0.06	0.01	0.85
47	c97 1,2-Benzisothiazole	-0.03	0.01	0.85
48	c141 Ethylidene cycloheptane	0.03	0.01	0.86
50	c26 Tridecanal	-0.02	0.01	0.86
51	c171 Butanoic acid	-0.02	0.01	0.87
53	c84 2,5-Octanedione	-0.003	0.01	0.88

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 16. Stepwise linear regression for prediction of bitter basic taste as the dependent variable and aromatic volatile compounds as independent variables.

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
Intercept		1.91		
1	c122 Cyclooctyl alcohol	0.10	0.09	0.09
2	c80 (E)-2-hexenal	0.04	0.09	0.18
3	c4 5-Pentyl-2(5H)-furanone	-0.08	0.09	0.26
4	c30 1-Octen-3-ol	0.003	0.05	0.32
5	c152 Dodecanal	-0.01	0.04	0.36
6	c101 Heptanoic acid	-0.05	0.03	0.39
7	c58 Trimethyl-pyrazine	0.01	0.03	0.42
8	c124 2,5-Dimethyl-heptane	0.04	0.03	0.45
9	c64 2,4 Decadienal	-0.03	0.03	0.48
10	c138 1,2-dimethylpyrrolidine	-0.09	0.03	0.50
11	c164 2-Decanone	0.13	0.03	0.53
12	c184 3-(Methylthio)-propanal	0.08	0.02	0.55
13	c66 Octanoic acid	0.02	0.02	0.58
14	c25 3-Isopropyl-piperidine	-0.10	0.02	0.60
15	c141 Ethylidene cycloheptane	0.04	0.02	0.61
16	c32 2-Dococen-1-al	0.02	0.01	0.63
18	c214 4-hydroxy-benzoic acid	-0.13	0.02	0.63
19	c145 (1-Methylbutyl)-oxirane	-0.05	0.02	0.65
20	c220 trans-2-undecenal	-0.06	0.02	0.67
21	c147 4-Oxononanal	-0.15	0.01	0.68
22	c99 4-Octen-3-one	0.10	0.01	0.69
23	c197 (E,E)-2,4-Octadienal	0.05	0.01	0.71
24	c22 2,3-Octanedione	-0.001	0.01	0.72
25	c6 Acetophenone	0.04	0.01	0.73
26	c221 4-hydroxymandelic acid	0.02	0.01	0.74
27	c21 (E)-2-decenal	-0.005	0.01	0.75
31	c173 1,3,5,7-Cyclooctatetraene	0.09	0.01	0.75
34	c48 3-Dodecen-1-al	-0.008	0.02	0.75
35	c183 Cyclooctanol	0.03	0.01	0.76
36	c29 1-Octanol	-0.005	0.01	0.77
37	c51 1-(1H-pyrrol-2-yl)-ethanone	0.04	0.01	0.78
38	c208 N,N'-dimethylcyclobutane-1,1-bis(methylamine)	0.23	0.01	0.79

Table 16 (Continued).

Step	Variables (Code and Chemical Name)[a]	Estimate[a] x 10^{-4}	Partial R^2	Equation[b] R^2
39	c151 Trans-2-tridecenal	-0.02	0.01	0.80
40	c1 2-Octenal	-0.003	0.01	0.82
41	c84 2,5-Octanedione	-0.004	0.01	0.82
42	c14 Nonanal	-0.0004	0.01	0.83

[a]Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

APPENDIX B

FIGURES

Figure 1. Flavor aromatic compound categories least squares means for the cut by internal endpoint degree of doneness interaction.

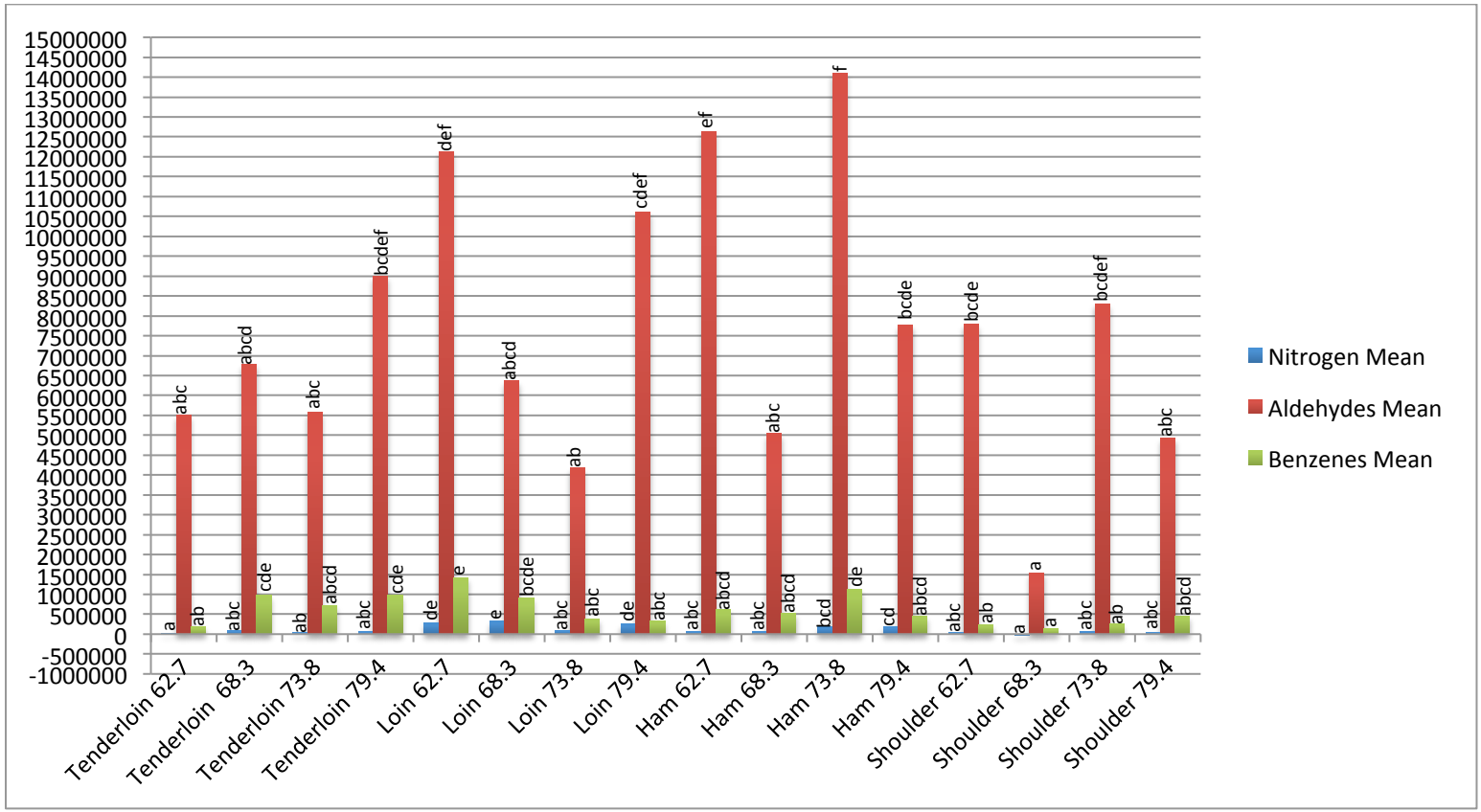

Figure 2. Partial least squares regression biplot (R^2=92.6%) of trained descriptive flavor attributes from the Pork Lexicon (blue), volatile aromatic compound categories (red), and 16 treatments (green).

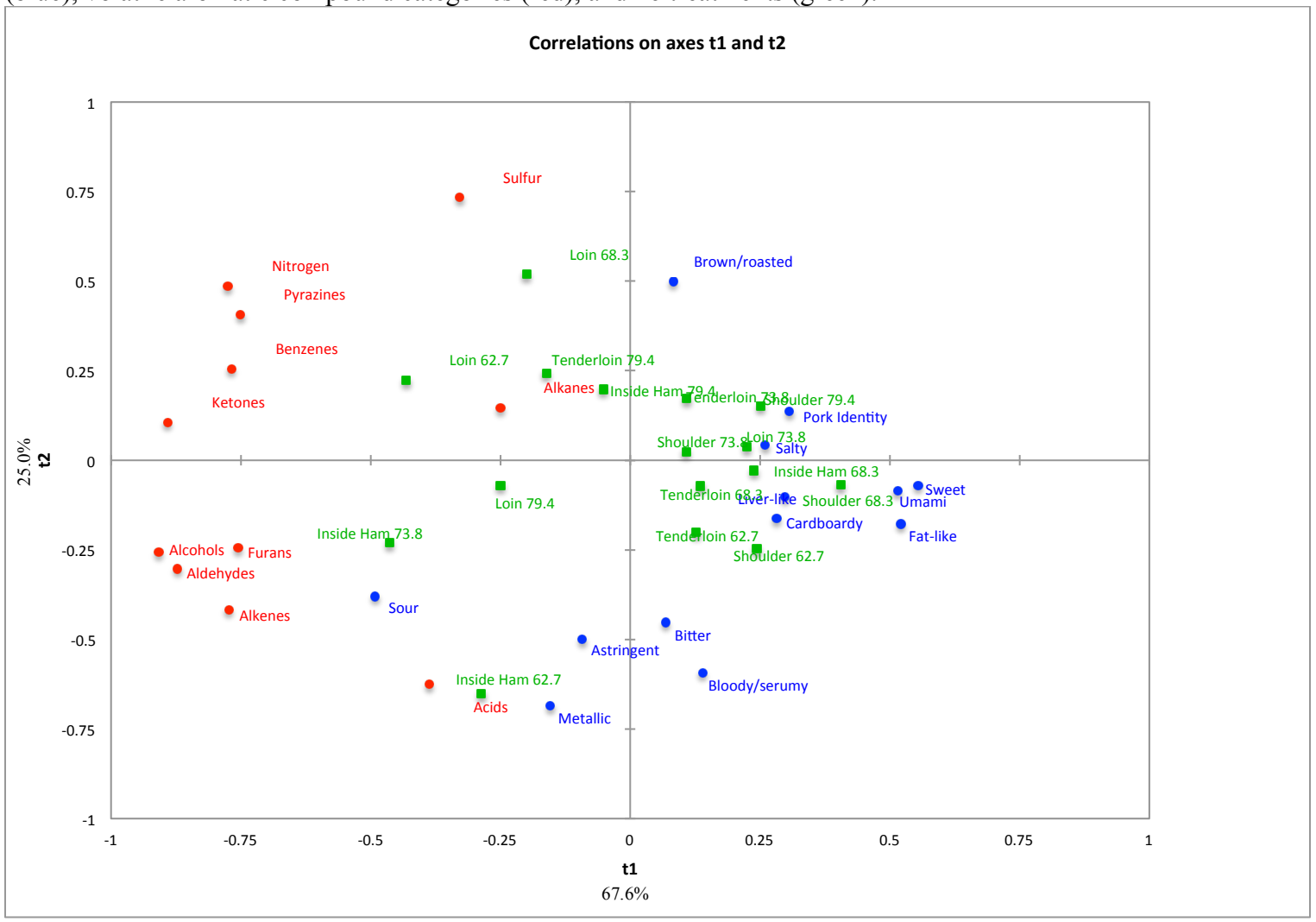

Figure 3. Partial least squares regression biplot (R^2=82.0%) of trained descriptive flavor attributes from the Pork Lexicon (blue), 157 volatile aromatic compounds (red), and 16 treatments (green).