Development of a sensory lexicon for smoky and applications of that lexicon

by

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Abstract

Smoking of food is one of the oldest methods of food preservation and still is used widely to help preserve foods such as meats, fish and cheeses. Apart from its conservation function, the smoking process also has a considerable influence on the sensory characteristics of the products. A highly trained, skilled descriptive sensory panel identified, defined and referenced 14 attributes related to the flavor of food products labeled as smoked or smoky. The lexicon included: Smoky (Overall), Ashy, Woody, Musty/Dusty, Musty/Earthy, Burnt, Acrid, Pungent, Petroleum-Like, Creosote/Tar, Cedar, Bitter, Metallic and Sour. Definitions of these attributes were written and references were found that anchor a 0-15 point scale. This lexicon was used to evaluate the differences among smoked products under different circumstances such as products on the market versus products smoked at home, different woods used to smoke products and the length of time a product spends in the smoker. There are many methods used to impart this smoky flavor and due to health, environmental and economic concerns, many producers use non-traditional methods while hobbyists thrive on the traditional methods. Descriptive analysis was used to see if there are differences between products smoked using an at-home smoker and market products. Using principal component analysis, cluster analysis and analysis of variance, it was found that market products were significantly different than products smoked using an at-home smoker. The market products were significantly more Sour and less Smoky, Ashy, Woody, Musty/Dusty and Acrid. Many types of woods are used to smoke products and many market products distinguish themselves based on the wood used. Six highly trained panelists evaluated pork that was smoked with either hickory, mesquite, cherrywood or Applewood and was smoked for 1, 2 or 4 hours. The flavor profiles of the smoke flavor was similar between the types of woods although as the length of time in the smoker increased and the intensities of most

attributes rose, the differences among products smoked with different woods became more pronounced. Apple wood smoked products had higher intensities for Overall Smoky, Ashy, Burnt, Pungent, Petroleum-Like, Creosote/Tar and Cedar, while cherry wood smoked products had lower intensities for all attributes. Hickory and Mesquite smoked products were not significantly different from each other and typically scored between the other two woods. Smoking is a slow process and many popular restaurants that smoke their own products find that their claims of smoking for long periods of time are beneficial to their image. Descriptive analysis was used to see how the flavor changes based on the length of time the product (pork) was in the smoker. The samples of pork ranged from not smoked to smoked for 15 hours, with samples at every 2.5 hour increment. For most attributes, the intensities went up with the amount of time the product was in the smoker. The only exceptions were Musty/Earthy and Sour. The regression analysis revealed that Smoky, Ashy, Acrid, Creosote/Tar and Bitter are all at least moderately correlated with the time the product spent in the smoker.

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Chapter 1 - Literature Review

Smoking (Cooking Method)

Smoking is a cooking technique where wood is heated to produce smoke. The heat of that smoke may or may not cook the food, but always imparts a distinguishable aroma and flavor to the product. Many products are smoked such as meats, fish, poultry and cheeses. There are many advantages to smoking products such as killing bacteria, preventing fats from becoming rancid, extending the shelf life and creating distinguishable flavors and colors (Marianski et al. 2007).

History

Smoking was one of the first forms of food processing and was originally used as a food preservation method (Maga 1988). The method dates back to the time of cavemen (Janes 2001). Cavemen found that when their meats were in contact with the smoke from their fires, the meat picked up different flavors and was better preserved than just drying.

Due to unpredictable weather in North European countries, inhabitants of these areas couldn't rely on air drying their meats like the southern countries (Spain and Italy) and smoking became a preferred method of food preservation (Marianski et al. 2007). Over time, smoking was combined with salting and this became very popular as it was a very effective preservation method and was adapted by cultures around the world.

Today's Uses

Smoking used to be done out of necessity. Today we have many methods of preservation, most of which are more efficient and economical than smoking. However, smoked products did not disappear as humans evolved to find the smoke flavor and aromas desirable. In the 1970s, companies started selling at-home smokers which popularized the method as a hobby (Anderson 2006).

Many types of products are smoked, or at least have smoky flavors. The most common smoked products are meats. 60% of all meats sold in Germany and Poland are smoked and 30% of meats sold in the USA are smoked, with a large portion of that being hot dogs (Marianski 2007). Other notable smoked products are cheeses, fish, sauces, spices and even beverages such as smoked beer. The smoky flavor is desirable to most cultures, so smoked products are found around the world.

Processes

When a product is claimed to be smoked, that just means smoke was used at some point during the process from raw to finished products. There are many methods to impart the smoke aroma and flavor to the product. The methods differ by the temperatures used, the equipment used and the method that the smoke is produced.

Cold Smoking, which is commonly used for fish, cheese and bacon, are done at temperatures just above room temperature, in the 15 to 25 °C range (Corretti 1975). This method is the original method of smoking that was used to preserve meats. It dries the products (major preservation method) while adding the smoky flavor. This method does not cook the product, as heat is not used. Many of these products are eaten without a cooking step (cheese) while others should be cooked afterwards (bacon).

Hot Smoking is most commonly considered smoking between the temperatures 55 and 80 degrees C; hot smoking is much quicker than cold smoking. The smoke becomes associated with the food 7 times faster (Draudt 1963). While the speed can commonly be advantageous, hot smoking tends to dry out the products. Drying out products is commonly undesirable, but this method can be used to make purposely dry products such as jerky. The drying out can be avoided, or at least slowed down, by adding a water pan to the smoker (Anderson 2006).

Warm Smoking is done at temperatures between cold and hot smoking, generally between 25 and 40 degrees C (Butanski 1979). This leads to properties of the final product that are in between if you were to hot or cold smoke. The smoke penetration is deeper than with hot smoking, but less than cold smoking. The time it takes to finish the process is also in the middle. Warm smoking allows products to create a dry skin, which helps increase shelf life, but the product keeps its natural juices and doesn't dry out as much as products do when hot smoked. (Marianski 2007).

Wet Smoking, or condensate smoke, is when wood and water are heated together causing a mixture of smoke and vapor. This is commonly done around 80 degrees C. This process has a short treatment time and good smoke yield (Fessman and Fessman 1979). Small at home smokers tend to utilize this procedure since they tend to be enclosed units, breaking off fresh air supply, which brings in moisture (Marianski 2007). Because of this, these types of smokers use a small water pan to add moisture during the smoking process.

The smoking process effects the sensory characteristics of the final product. Cardinal et al. (2006) studied the effect of the process on the odor of smoked herring. The biggest differences between the smoking processes were in the attributes Cold Ash, Global Intensity and Fat Fish. The products smoked using an autocombustion generator had the highest Global Intensity with a specific Cold Ash note. The samples smoked using a friction generator had low smoke odors and was much more characterized by the fish notes. This study also found that as the temperature used to smoke the products increases, the Global Intensity goes up. This is due to heavier compounds being able to volatilize and get into contact with the product.

How the product is heated can make huge differences. When the product is heated, the surface moisture is removed and the proteins coagulate, creating a tacky surface which allows

the smoke to adhere to the product much easier. However, if the product is heated too fast, the fat will migrate to the outside and case hardening will result (Herring and Smith 2012).

Liquid Smoke

The process of smoking meats adds many compounds to the final product, many of which are thought to be dangerous to human's health (IARC 2010). Due to this health concern, many producers are using liquid smoke to add smoky characteristics to their products. Liquid smoke is a water-soluble solution created by condensing smoke. There is no standard of identity for liquid smoke, so commercial products can vary widely. Liquid smoke can be desirable because the refining process removes polycyclic aromatic hydrocarbons, which are considered to be carcinogenic and the end flavor intensities and color can be adjusted (Cadwallader 2007; Varlet et al. 2010).

Liquid smoke is applied to products in a wide variety of methods (Schneck 1981). There is a patent by W.M. Allen which explains regenerating smoke using air atomization which is a leading method of using liquid smoke in batch smokehouses (Allen et al. 1972). Continuous processes have been developed, and have evolved. One continuous method is by having the products on the line and having liquid smoke sprayed on top. In all methods, the liquid smoke is applied topically and then the products are commonly heat treated to add colors and texture effects that are common to smoked products as well as adding anti-microbial properties.

Ojeda et al. (2002) conducted descriptive sensory analysis on liquid smokes and used the following list of attributes to describe the aroma of liquid smoke: Burnt, Fruity, Combustible, Sharp, Floral, Caramellic, Sweet, Pungent, Acidic, Wood, Medicinal, Spice/Aromatic herb and Musty.

Gonulalan et al. (2003) studied the different effects liquid smoke has in comparison to traditional smoking. This study was performed on beef tongue. Overall, the traditional smoking gave slightly better sensory properties than the liquid smoke, but all differences were small. The differences between the chemical and microbiological properties were also small. However, the use of liquid smoke had benefits such as lower environmental pollution, cost and the products were more uniform.

Flavor and Aroma Compounds

There are many studies that have been conducted in order to identify the volatile compounds that contribute to the flavor and aroma of smoked products. The major chemical families that have been found to be related to the smoke aroma and flavor included free fatty acids, phenols, aldehydes, hydrocarbons, ketones, alcohols, esters, heterocyclic and sulfur compounds (Guillén et al. 2006, Jerkovic et al. 2007, Xie et al. 2008, Yu et al. 2008, Majcher et al. 2011). Because of the extensive use of smoke flavoring, research on the chemistry of liquid smoke has been conducted (Guillen and Ibargoitia 1996; Guillén and Manzanos 2002; Guillén & Manzanos 2005; Pino et al. 2014). Many authors have reported that phenolic compounds are the major chemical family that contributes to the smoked odor (Kostyra and Baryłko-Pikielna 2006; Cardinal et al. 2006; Varlet et al. 2006; Jerković et al.2007; Jónsdóttir et al. 2008). Maga (1995) revealed that there are about 400 compounds in smoke.

Montazeri et al. (2013) used gas chromatography-mass spectrometry to analyze the chemical compounds in an array of liquid smokes. They found a multitude of phenolic compounds, aldehydes and ketones, furans and pyrans, organic acids and other compounds. Carbonyl-containing compounds were major constituents in all of their liquid smoke samples. This study looked at the differences between full-strength and refined liquid smokes, concluding

that the major differences were that the refined samples had a lighter color, and lower acidity, carbonyl-containing compounds and organic acids.

Fujimaki et al. (1973) studied the differences in flavor compounds between liquid smokes, focusing on distilled and undistilled products, and products from different types of woods. This study used gas chromatography, infrared spectroscopy and nuclear magnetic resonance spectra. They found that the differences between the samples were mostly due to the amounts and compositions of the carbonyl and non-carbonyl groups, the pH and phenolic compounds. Using their findings from the instrumental methods, they could infer that the undistilled samples had resin-like odors while the distilled ones that strong pungent smoky flavors.

Lexicon Development

A lexicon, in the broadest sense, is a list of words that describe the sensory attributes of a product (Drake and Civille 2003). Lexicons can be specific for one type of product, such as Portuguese cooked blood sausage (Pereira et al. 2015), or for an entire array of items like leafy vegetables (Talavera-Bianchi et al. 2010). Many times, lexicons are just for the flavor (Drake et al. 2001, Talavera-Bianchi 2010), odor (Hongsoongnern and Chambers 2007a) or texture (Brown et al. 2003). There are lexicons that list attributes for more than one sensory properties such as texture and flavor (Hongsoongnern and Chambers 2008b) or texture and appearance (Dooley et al. 2008).

Besides the list of terms, there will be a definition for the term and often, references so that the concept in the definition can come to life. Defining the terms is of the upmost importance in the process of developing a lexicon (Lawless and Civille 2013). Defining the

terms allows researchers to use the lexicon, and all terms in it, the same way it was intended to by the creator. References, which can be food, chemicals or other substances, help descriptive analysis panelists link the conceptual term and definition with reality and anchor the scale (Drake and Civille 2003).

Panelists

To develop a lexicon, panelists are necessary. The norm is that the panel is already trained and experienced because they have previously used a wide range of terms (Chambers et al. 2016; Brown and Chambers 2015). Drake et al. (2001) brought together a group of experts in the commodity they were studying (cheddar cheese) to develop the first draft of the lexicon.

There are cases where the researcher doesn't have access to an already established panel, and there are developed protocols for how to train new panelists (ISO 8586). Many sources that discuss training a new descriptive analysis panel have common themes (ASTM STP 758 1981; Meilgaard et al. 2007). The first step is to test the acuity of a perspective panelist's tasting, smelling and/or other sensory perceptions, which is easily done through selected difference and ranking tests. The next step, before starting the training process, is normally an interview to see if they have a positive attitude and it they would work well with the other panelists.

After acuity tests and interviews, the perspective panelists can start training. The amount of training can differ based on the objective of the panel. The amount of training can be determined by the method they are being trained on; for example the Flavor Profile Method recommends 60 hours of training and 100 hours of practice (Keane 1992) while Quantitative Descriptive Analysis recommends only 4-8 hours of training (Stone 1992). ASTM documents recommend 43 h of training for just skinfeel panels (ASTM E1490 2011). Many panelists are

trained so that they can be used for an array of products. Many studies report 120 h of training (Suwonsichon et al. 2012, Vazquez-Araujo et al. 2012).

Samples

The number of samples used during lexicon development ranges between studies and what is a suitable number is dependent on the product. For lexicons for products with a wide variety or has a large market share, many products will need to be used. On the extreme end, Drake et al. (2001) had 240 cheeses for their development of a cheddar cheese lexicon, which is a very common food product. Chambers et al. (2016) also had a large sample set of over 100 coffees, which is necessary when the product category is produced worldwide.

On the other end of the scale, very specific products do not need as large of a sample size to cover the full range of products. In order to develop a lexicon for Spanish dry-cured sausage, Ruiz Perez-Cacho et al. (2005a) used 11 samples. Similarly, 12 samples were used for dairy protein hydrolysates (Newman et al. 2014) and 20 samples were used for blueberry juice (Bett-Garber and Lea 2013).

Term, Definition and Reference Development

Coming to the final list of terms on a lexicon is commonly done in a couple of steps. The first step is a round table discussion where the panelists are given a few products and they start generating terms. Sometimes, the panel has a related lexicon to build off of (Retiveau et al. 2004; Miller and Chambers 2013). After the panel has a list of terms, they discuss it and remove and rename terms until they believe they have a list that is nonredundant and covers all aspects of the product (Drake and Civille 2003).

Once the researchers are happy with the list of term, those terms are defined. Giboreau et al. (2005) set guidelines for the structure and content of definitions. Definitions are how the

panelists know exactly what each term is referring to and what allows other panels to use published lexicons.

References are also identified for all proposed attributes. References can be foods, chemicals or other products. For example, Citral can be used as a reference for citrus fruits (Galan-Soldevilla et al. 2005), vegetable oil can be used for oil-like and cardboard in water can be used for cardboard (Chambers et al. 2005). Many times, references are can found in scientific literature for attributes that are used in other categories (Galan-Soldevilla et al. 2004).

Validation

After the researchers and panelists think they have a list of terms that is discriminatory, nonredundant and descriptive, the next step is validation. This involves panelists evaluating products that fall into the category they are discussing using the proposed lexicon. The panelists may use products that have not been used yet in the study (Drake et al. 2001) or products that have already been used (Chambers et al 2006).

The exact method of evaluation can vary from study to study. Some studies have the panelists evaluate the products individually (Pereira et al. 2015, Ruiz Perez-Cacho 2005b) while others use the consensus method (Chambers et al 2006, Talavera-Bianchi 2010). The intentions of the evaluations are all the same where the panelists evaluate each product by giving an intensity for every attribute.

Data Analysis

The statistical methods that can be used to analyze the validation data is dependent on the evaluation method used. Many researchers will use analysis of variance (ANOVA) to test the panel's performance so make sure the data is reliable (Drake et al. 2001). Small significant differences between terms can prove consistent panel performance.

The most common statistical method used to analyze validation data, regardless of evaluation methodology, is principal component analysis (PCA). PCA can be used to show differentiation between samples (Coggins 2008) and relationships between common attributes (Di Donfrancesco et al. 2012). PCA tries to explain the data in as few uncorrelated variables as possible. Principal component (PC) 1 will explain the most amount of variance in the data, PC2 explains the second most amount and that continues until 100% of the variance is explained. Each PC has an eigenvector which explains how much each attribute contributes to that PC, and in which direction. For example, Di Donfrancesco et al. (2012) needed 4 PCs to explain 80% of the variation of the texture and appearance of dog food and each PC was driven by different attributes.

A similar statistical method that can be utilized is factor analysis, which can group attributes and show redundancies in the lexicon (Heisserer and Chambers 1993). Correlation analysis between the attributes can be used for the same reason (Drake et al. 2001). These two methods can also show groupings of attributes, which may still be different, but fall into similar groups. For example, Chambers et al. (2016) had layered attributes in the brewed coffee lexicon such as Spice Brown with Nutmeg, Clove and Cinnamon nested under it.

Lexicon Development of Specific Attributes

Most of the lexicons are for specific products or commodities. Some of these lexicons use attributes that can be broken down into more specific parts. For example, Chambers et al. (2016) used the term Nutty in the lexicon for brewed coffee but Miller et al. (2013) found 22 attributes that are associated, and can explain, the term Nutty. A similar lexicon was published for the attribute Green (Hongsoongnern and Chambers 2008a).

The development of these types of lexicons have a slightly different approach. The products that are evaluated by the panelists are products that are commonly associated with that term. For the Green lexicon, many vegetables, herbs and fruits were considered (Hongsoongnern and Chambers 2008a). For the Nutty lexicon, the panelists evaluated products that they have previously described as Nutty and were also "given various iterations of nutty definitions published or used in other contexts" (Miller et al. 2013). This can be more difficult as the panelists must pick apart the product and only focus on the flavor attribute at hand.

Another method to explain a specific attribute can be done on the chemical level. Bott and Chambers (2006) looked at chemicals that are associated with the Beany aroma and found that chemicals that are not considered beany on their own contribute to the overall beany aroma.

Descriptive Analysis

Descriptive analysis is one of the three types of sensory testing (descriptive, discrimination and hedonic). It uses trained panelists to describe the sensory profiles of products. Those sensory profiles can be compared and differences can be found between products. Descriptive analysis is more robust than discrimination testing since the exact differences are found between products and discrimination testing commonly answers the simple question "is there a difference?" (Lawless and Heymann 2010).

There are two parts to descriptive analysis: qualitative and quantitative. The qualitative part of the analysis is the list of attributes used to describe the product. The lexicon is the qualitative part. Then there is the quantitative part which is when the panelists give an intensity to each of the attributes for the product. This data is commonly shown in spider plots to easily visualize the differences in profiles.

Descriptive analysis is commonly paired with other research methods. It can be paired with consumer testing to find out if certain aspects of a product drive liking. Researchers very commonly try to correlate descriptive analysis with instrumental methods such as gas chromatography, however Chambers and Koppel have found limitations to this (2013).

Methods

There are a multitude of standard methods for descriptive analysis, and many times the exact method used is a hybrid of those standards. The most common methods are Quantitative Descriptive Analysis, the Flavor Profile Method, Texture Profile Method and Spectrum method. The standards for these methods explain how to train the panelists and the evaluation method. These methods largely differ in the scales used and how the data can be analyzed.

Quantitative Descriptive Analysis (QDA) should use at least 25 trained panelists. Using a 6-inch line scale, which is anchored at the ends, they rate a product on every given attribute. The mark on the line scale is quantified by measuring from the left end of the scale to the mark. Spider plots are often created using the averages between all the panelists and ANOVA is the most common way to analyze this data (Stone 1992).

The Flavor Profile Method is based off the principle that the overall flavor of a product can be broken down into many parts. Despite its name, this method can be used for aroma, flavor and aftertaste. Four or more panelists are used to come to a consensus on the profile of a product. This involves all panelists agreeing on the rating of each attribute. The scale is from 0 to 3 with 0 = not present, 1 = slight, 2 = moderate and 3 = strong. To analyze this data, multivariate statistical methods are used and interpretations are made based on the results (Keane 1992).

The Texture Profile Method is based off the same principle as the flavor profile method. This method evaluates the mechanical and geometrical attributes as well as attributes related to

the moisture and fat content. Every attribute has a method to evaluate it. This method also uses a group of highly trained panelists to rate each intensity and come to an intensity so that one profile is created for each product. The scale used is slightly more detailed than the flavor profile method scale in that it adds:)(= Threshold,)(-1 = Very Slight, 1-2 = Slightly-Moderate and 2-3 = Moderately Strong. The data from this method is also analyzed using multivariate methods (Munoz et al. 1992)

The Spectrum method claims to completely characterize the product's sensory descriptive attributes. Eight to twelve highly trained panelists create the ballot and then evaluate the product. The products are evaluated individually using a universal scale. The scale is from 0 to 15, with 0.1 increments. The panel is trained so that they use the same scale for every attribute. For example, if a sample is given a 5 for sweetness and a 5 for bitterness, the product is equally as sweet as it is bitter (Munoz and Civille 1992).

All of these methods have positives and negatives, and most of the time, the exact standard method is not used. Hybrid methods have been created and widely used. For example, the scale can be changed to be more or less specific. The flavor profile method only has 4 points, so there are many studies that have taken a lot of the concepts of this method but used a more detailed scale. This allows for better differentiation between products. Also, the flavor profile method uses a consensus method, so only multivariate statistical methods can be used since there is one data point for each attribute for each product. Having panelists evaluate the product individually means analysis of variance can be used, so statistically significant differences can be calculated.

One method, which has been used in a lot of studies, is based off the flavor profile method. The method uses a 15 point, with 0.5 increment, scale instead of the 4 point scale. The

method has also been used for panelists coming up with a consensus profile and individual evaluations. Many lexicons have been created, with the references anchoring the scale for this method (Talavera and Chambers 2016; Chambers et al. 2016; Di Donfrancesco et al 2012).

Research Objectives

Smoked products are regularly consumed in the United States and around the world. Smoking products is not only done on the large production scale, but enjoyed by hobbyist looking for the authentic experience and taste. While a lot of research has been conducted using gas chromatography and studying the aromatic compounds produced during the smoking process, there is minimal research using descriptive sensory analysis on smoked products and minimal research on the flavor of these products.

The first objective of this project was to develop a sensory lexicon that can be used for the entire range of smoked products. The lexicon contains attributes with their definitions and references so that it can be used by descriptive panelists around the world. The lexicon can be used to strictly compare the smoked flavor of products, or could be added to lexicons dealing with the raw product.

The second part of this project was to use that lexicon to study how the smoky flavor profile changes under different conditions. The objectives were (1) to see if smoked products on the market are significantly different than products smoked at home, (2) to see if the type of wood used to create the smoke has an effect on the flavor and (3) to see how the smoke flavor changes the longer the product is in the smoker. All of these studies used descriptive analysis as their major method.

This project could be of use to the industry as they develop new smoked products to sell on the market. With the lexicon and flavor profiles of "home-smoked" products, they can try to match a more authentic smoked flavor, especially with the rise in use of liquid smoke and flavorings.

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Chapter 2 - Development of a Smoke Flavor Lexicon

ABSTRACT

Smoking of food is one of the oldest methods of food preservation and still is used widely to help preserve foods such as ham, bacon, sausage, fish and cheeses. Apart from its conservation function, the smoking process also has a considerable influence on the sensory characteristics of the products. A highly trained, skilled descriptive sensory panel identified, defined and referenced 14 attributes related to the flavor of food products labeled as smoked or smoky. The panel evaluated sauces, meats, fish, cheeses, vegetables and flavorings that are on the market in addition to samples that were smoked in-house. Attributes attributed to the smoke flavor in each sample were written down and discussed. The list was narrowed to include only those attributes that were thought to be specifically related to the smoke flavor and not to the base notes of the product or other cooked/processed notes. The lexicon includes: Smoky (Overall), Ashy, Woody, Musty/Dusty, Musty/Earthy, Burnt, Acrid, Pungent, Petroleum-Like, Creosote/Tar, Cedar, Bitter, Metallic and Sour. Definitions of these attributes were written and references were found that anchor a 0-15 point scale. The references included market products, chemical solutions and commonly found non-food products. This lexicon can be used to evaluate the smoke flavor on all types of food products.

INTRODUCTION

Smoking is a preservation method that has been employed since ancient times. In the modern "refrigeration" era, smoked foods are demanded by consumers not so much for their preserved state, but for their unique and characteristic flavor, including smoky flavor (Chambers et al.1998). For example, a smoked product, such as smoked salmon, can present a wide range of sensory characteristics (Cardinal et al. 2004) which impacts European consumers' selection of

such products based on the intensity of smoking, the intensity of salting and the product appearance (Séménou et al. 2007).

A large body of research has been carried out to identify the volatile compounds that contribute to the characteristic flavor and aroma of smoked products. The chemical families from smoked products mainly included free fatty acids, phenols, aldehydes, hydrocarbons, ketones, alcohols, esters, heterocyclic and sulfur compounds (Guillén et al. 2006, Jerkovic et al. 2007, Xie et al. 2008, Yu et al. 2008, Majcher et al. 2011). Extensive literature exists on the volatile compounds of smoke flavoring (Guillh and Ibargoitia 1996, Guillén and Manzanos 2002, Guillén & Manzanos 2005; Pino et al. 2014). For smoked products, various authors report that phenolic compounds are mostly responsible for the smoked odor (Kostyra and Baryłko-Pikielna 2006, Cardinal et al. 2006, Varlet et al. 2006, Jerković et al.2007, Jónsdóttir et al. 2008).

Several specific compounds referring to a smoky aroma have been evaluated and defined. Chambers et al. (1998) used highly trained sensory panelists to describe the chemicals potentially associated with smoky aroma as ashy, brown spice, burnt, burnt sugar, clove, creosote, cured maple, sulphur and woody. Ojeda et al. (2002) used experienced descriptive sensory panelists to describe the potential chemical references of smoke flavorings as burnt, fruity, combustible, sharp, floral, caramellic, sweet, pungent, acidic, wood, medicinal, spice and musty. However, many smoky compounds had different types of smoky characteristics and some smoky compounds may also contribute other odor properties (Chambers et al.1998; Ojeda et al. 2002).

Although previous studies have considered flavor characteristics of chemical compounds and of added smoke flavorings, none have reported a detailed lexicon for the smoke flavor attributes of a variety of products. Most researchers described smoked flavor as smoky (Smiecinska and Chwastowska 2006, Bárcenas et al. 2001), smoked (Kostyra et al. 2016,

Carrapiso et al. 2015, Petridis et al. 2013, Almli and Hersleth 2013, Portella et al. 2011) or smoke (Stojkovića et al. 2015; Midelet-Bourdin et al. 2008, Brillet et al. 2005, Mørkøre et al. 2001, Cardinal et al. 2001) for specific products. However, authors also indicated that smoked flavor could be described as artificial (Portella et al. 2011), bitter (Portella et al. 2011, Almli and Hersleth 2013), tart (Smiecinska and Chwastowska 2006), vegetal and herb (Séménou et al. 2007, Midelet-Bourdin et al. 2008), rubber (Midelet-Bourdin et al. 2008 Brillet et al. 2005), wood fire (Mørkøre et al. 2001, Cardinal et al. 2001, Séménou et al. 2007) and pungent (Bárcenas et al. 2001) There are a few researchers that have reported smoked flavor definitions and references as part of other lexicons (e.g. coffee, Chambers et al., 2016; soy sauce, Inamura, 2016; Pujchakarn, Suwonsichon, and Suwonsichon, 2016; sausage, Pereira, et al., 2015), but these typically included one to three terms and suggest the potential need to establish a general lexicon to describe smoked flavor characteristics. Such general lexicons have been published previously for other flavor components such as green (Hongsoongnern and Chambers 2008),beany (Bott and Chambers 2006) and nutty (Miller et al. 2013).

The objectives of this study were (1) to identify the sensory characteristics contributing to smoked flavor, (2) to develop a sensory lexicon that includes characteristics, definitions and references to describe the flavor of a wide variety of smoked products; and (3) to validate the established lexicon by determining whether the lexicon could describe and differentiate the smoked characteristics of a broad range of smoked products.

MATERIALS AND METHODS

Samples

This study used both market products and samples smoked in-house. Market products (n=54) consisted of multiple samples of products identified as smoky including sausage; bacon; chicken, turkey and ham lunch meat; barbeque sauce; marinade; cheese; fish and liquid smoke. All products were bought at local branches of national chain grocery stores. Samples (n=24) of chicken breasts, pork loins and potatoes were smoked in-house using hickory or cherry wood at 93° C for 2.5, 3, 3.5 and 4 hours. They were smoked using an electric smoker (30 lb Digital Country Style Smoker, Model 40903, The Sausage Maker Inc, Buffalo, NY, USA) and all raw products were bought at a local branch of a national chain grocery store. Table 1 includes all products used during this study.

Panelists

6 highly trained, skilled panelists at the Sensory Analysis Center at Kansas State University participated in this study. Every panelist had completed 120 hours of training in flavor and texture analysis and all had a minimum of 2000 hours of general sensory testing experience including similar products. The panelists received 1.5 hours of orientation for this project that included reviewing previous work on smoked products

Sample Preparation

For each panelist, sauces and marinades were poured into 30ml (1 oz) plastic cup (Conex, 100PC, Dart, Mason, Michigan, USA). Liquid smoke samples were first diluted 1 part liquid smoke to 8 parts water and then poured into 30ml (1 oz) plastic cup. Undiluted liquid smoke was too intense for evaluation and the 1:8 dilution was found to keep the smoke flavor at a level the panelists could evaluate. Slices of cheese were cut into 2.5 cm squares and blocks of cheese

were cut into 1.2 cm cubes. Lunch meat was cut into 2.5cm squares (the thickness of the lunch meat slice). Fish was cut into approximately 1.2cm cubes. Sausage links were heated according to the directions on the package on a stovetop and cut into 1.2cm thick rounds. The bacon was baked in a 204° C oven for 20 minutes and the fat was drained out at the 10 minute mark. The bacon was then cut into 2.5cm sections. All solid foods were placed in 100ml soufflé cups (Solo, P325N, Dart, Mason, Michigan, USA), 4 pieces per cup.

The samples that were smoked in-house were smoked using an electric smoker. Hickory or cherry wood chips (Cowboy Brand, Cowboy Charcoal, LLC, Albany, KY, USA) were dampened and placed into the pan that was supplied with the smoker. Enough wood chips were dampened to completely fill the pan. The smoker was heated to 93° C and all the samples for one day were placed on the same rack. A probe with an external monitor was inserted into the thickest part of each food type to measure the internal temperature without having to open the smoker. At 2.5, 3, 3.5 and 4 hours, samples were removed. If they had not reached the minimum internal temperature for food safety (71°C for pork loins and 74°C for chicken), they were immediately placed into an oven preheated to 177°C and baked until the minimum internal temperature was reached. All samples of internally smoked products were held in a warming oven set at 93°C until serving. The potatoes were put directly into the warming oven after being taken out of the smoker. Directly before serving, the samples were cut into either 1.2cm cubes (chicken and pork) or 0.3cm slices (potatoes) and placed into 100 ml soufflé cups.

The panelists also evaluated the base products of some of their smoked counterparts. For example, they evaluated baked chicken and smoked chicken so make sure the attributes that were being used for evaluation were for the smoke flavor and not related to the chicken. These

products were baked in a 177°C oven until they reached their safe cooking temperatures. They were then cut and served in the same manner as the smoked products.

The sausage, bacon and in-house smoked products were served on top of heated tiles covered in aluminum foil that were heated in a 177°C oven. The lunch meat and fish were served on ice while the cheese, sauces and marinades were served at room temperature.

Sample Evaluation

Samples were labeled with random 4-digit codes and served to the panelists sitting at a round table. The panelists had a waiting period of approximately 10 minutes between samples and were given water, whole milk, crackers, mozzarella cheese and cucumbers to neutralize the flavor of the previous sample before evaluating the next sample. The panelists sampled and discussed the flavor attributes of every product, focusing on the flavor imparted by the smoking process. Flavor attributes associated with the base product were not discussed except when necessary for the panel to determine if they considered the attribute to be part of the smoke character or base/cooked flavor of the product.

Development and Description of the Lexicon

After all the products were evaluated initially, the researchers worked with the panelists to focus the list of attributes such that overlapping attributes were made as independent as possible. Thus, when attributes appeared to overlap, the panelists were asked to ensure that they were not evaluating the same attribute in multiple ways and were asked to eliminate attributes that were duplicative, and rename and redefine those that were overlapping to reduce correlation among attributes. In addition, panelists also were asked to select only those attributes associated with the smoke flavor. For this part of the testing and discussion, raw or cooked product

(unsmoked) were used to help differentiate base or cooked flavor notes from those associated with the smoke flavor.

Definitions were created for the attributes. Some attributes had definitions in the Sensory Analysis Center's database but a few had to be created and others were modified based on this work. References also were determined for the attributes if not already available

Test Design for Attribute Determination

For evaluation, a randomized complete block design was used with the blocking factor being the type of product, e.g. fish products were served one after another in the test to avoid potential confusion associated with jumping from product type to product type. Each of the 78 samples were evaluated once. In addition, samples were tested again during discussion of the groups of attribute. A total of twenty 1.5 hour sessions were used for attribute development, definition determination, and referencing.

Validation

In order to validate the proposed lexicon, the same panel evaluated the smoke flavor of 20 samples, both smoked and unsmoked and covering a variety of products. The samples were evaluated using a 0 to 15, with 0.5 increments, scale. If panelists detected a new attribute that had to be added to properly describe the smoke flavor, that attribute was revisited. Unsmoked samples were evaluated to ensure the lexicon did produce other than very low to no scores with those samples.

Data Analysis

Using SAS (Version 9.2, SAS Institute, Inc., Cary, NC), a principal component analysis was run on the data from the validation. The scree plot was used to determine how many principal components were necessary to explain the variance in the data and then the

eigenvectors of each necessary principal component were examined to determine which attributes were the major drivers, which are the attributes that have the biggest influence on that principal component. Any attribute that was a major driver of each necessary principal component was determined to be a contributor of smoky flavor. The component maps were used to determine if the lexicon leads to discrimination between smoked and unsmoked products.

Using XLStat (Version 2015.3.01, Addinsoft, New York, New York, USA) a correlation analysis was run to show correlations between attributes. If attributes are very closely correlated, it could mean that two attributes are explaining the same flavor. The correlation analysis can help lower redundancy in the final lexicon.

RESULTS AND DISCUSSION

After 25 sessions of lexicon development, 14 attributes were generated to describe the smoke flavor. These attributes are listed in Table 2. Although this may seem like an excessive amount of time for determining attributes, the nature of attributes for smoke was difficult to define. It was difficult to separate the base flavor notes of products from those that are associated with smoke. For example, smoked fish had quite a different quality to its character than raw or steamed fish. What is smoke and what is fish? Panelists initially wanted to describe and reference every part of the flavor of smoked products as part of the smoke lexicon because of that difficulty, but that did not seem helpful when trying to understand the smoky flavor that is contributed by various treatments across a range of products.

A number of different flavor "myths" surround the use of smoky flavors and those had to be determined and dispelled as part of the lexicon development. For example, people commonly assume that the specific flavor of woods (e.g. mesquite, oak, hickory, cherry, apple, etc.) are able

to be readily identified and named. Thus, the panel started attempting to do this and quickly realized that this was an impossible task. The flavor of specific woods is less likely to be a specific flavor note and more likely to be a combination of intensities of specific notes in particular products. Thus, the smoky note from hickory had less acrid character than that from mesquite, but even that level changed depending on whether the hickory smoke is part of pork or beef. Thus, the attributes presented in this lexicon represent an “extraction” of the essential characteristics of the sensory properties into those we believe are the basic building blocks of smoky character.

Every attribute in the lexicon had a definition and one to three references. Many of the attributes (Smoky, Ashy, Woody, Musty/Dusty, Musty/Earthy, Burnt, Pungent, Petroleum-like, Bitter, Metallic and Sour) are commonly used and already had definitions and references that were used in other published lexicons (e.g. Chambers et al., 2016; Talavera and Chambers, 2016; Retiveau et al., 2005). Some of those terms needed to be modified to better suit this lexicon, such as the overall smoky reference that was better defined by a different liquid smoke product. The reference for burnt was based on peanuts and used in a coffee lexicon (Chambers et al. 2016), but needed a better defined process for creating the reference that produced a more consistent reference.

Other attributes needed to have definitions created for them, which panelists did by tasting products that were expected to be intense in that attribute and listing words that were related with what they were tasting. After they had a list of words, they narrowed it down to words they all agreed on and listed them in order of importance. Complete sentences were then structured by using the words that described the attribute and phrases such as "associated with", "which may include" and "varying degrees of".

References consist of market products, chemicals and solutions. The references are listed in Table 2 with their corresponding attribute. To find references for the attributes that did not already have references (Acrid, Creosote/Tar and Cedar), the panelists discussed possibilities that then were gathered and tested. For example, peanuts that were roasted to the point of being burnt were already used for the Burnt attribute and the panelists found the over-roasted peanuts to be an appropriate reference for Acrid as well. However, that caused confusion, so another reference, a smoky flavoring, different from that used for overall smoke was used that had an acrid note. For Creosote/Tar and Cedar, the products with those namesakes were tried and found to be high on the scale, but appropriate. For Cedar, the reference was Hartz Natural Red Cedar Small Animal Bedding & Litter in a medium snifter and for Creosote/Tar the reference was a teaspoon of tar in a 12 ounce capped jar. Other references, dilutions, chemicals, and strategies were attempted to determine additional references at various levels of intensity. Many were not successful and further work needs to be conducted to find additional appropriate references.

When the first draft of the lexicon was determined, a group of attributes called "Smoke Identities" with specific adjective labels such as Hickory, Mesquite and Fruitwood were present in the list of terms. For each identify attribute, in-house smoked pork, liquid smoke labeled with that wood term, and fragrance strips smoked with that particular wood were used to help discriminate among the specific identities. As discussed previously, that was found not feasible, and the specific "Smoke IDs" were not added to the final lexicon. Only one wood attribute, cedar, specifically referring to the wood, not the smoke produced by the wood, was finally determined to be part of the overall concept and attribute generically referred to and scored as smoky.

One issue in accurately evaluating multiple products in one session, is the need for panelists to cleanse their palate. Many items have been suggested to be utilized as palate cleansers and many products generally have been discounted when formally tested (see e.g. Lee and Vickers, 2010; Vickers et al., 2008; Naswari and Pangborn, 1990). However, in some studies options such as crackers (Ross et al., 2007) or mozzarella cheese, cucumbers, apples, and unsalted crackers (Lucak and Delwiche 2009) were used as a palate cleanser. Our experience and published research also suggested that time and water are probably the best palate cleansers (Allison et al., 2007; Allison et al., 1999) and that other cleansers typically were not effective although there definitely is an impact of some components like menthol on other flavors (Allison and Chambers, 2005). However, our experience also shows that panelists *believe* that palate cleansers work and most work suggests that they are not detrimental. Thus, for this project, panelists were given a variety of palate cleansers and decided as a group which two were most effective. Because smoked products can range from spicy to meaty to fatty to vegetative and salty sauce flavors, they chose between cucumbers, apples, mozzarella cheese, unsalted top crackers and whole milk. Unsalted top crackers and whole milk were selected, followed by water. Samant et al., (2016) found that mild cheese was most effective for a spicy chicken product and crackers have long been a staple of the sensory scientist's tool box as a palate cleanser.

During the validation no additional attributes were noted by the panelists as needing to be added. Thus, the panelists believed the smoky flavor profile was adequately described by the attributes on the list. All attributes had a rating greater than zero for at least one product out of the 16 products evaluated suggesting that all the attributes were used and needed by the panelists to fully evaluate the samples.

The principal components analysis showed that four principal components were necessary, each having eigenvalues greater than 1. Together they explained 81% of the variance and all 14 attributes are necessary to fully describe those explain those four principal components. For Principal Component 1, the major drivers were Ashy, Burnt, Acrid, Pungent, Creosote/Tar, Cedar, Bitter and Sour; Principal Component 2 was driven by Smoky, Ashy, Woody and Musty/Dusty. Principal Component 3's major drivers were Metallic and Sour (in the negative direction) and Principal Component 4's major drivers were Musty/Earthy and Petroleum-Like (Table 3).

In the graph of observations based on the first two principal components (Figure 1), all of the unsmoked products were clustered in the bottom left quadrant. This showed that the lexicon distinguished between smoked and unsmoked products. Besides the cluster of unsmoked items, no other obvious clusters were found, such as clusters based on the type of raw product. In order to see if certain attributes are more likely in one type of product than other, future studies will have to be conducted.

There were few attributes that had strong correlations, except Cedar and Burnt (Table 4). These attributes had a correlation of 1.0, and this is due to the fact that only one product that was evaluated had Burnt and Cedar intensities at all. These were different attributes and the definitions have only one overlap with the word "dark". The only other correlation that was considered in the "strong" range (>0.80) is Bitter and Sour. These were basic tastes and are known to be different. Overall the correlation analysis showed little redundancy.

CONCLUSIONS

Established and proven lexicons can be a powerful and convenient tool for researchers. They can make future work much easier, faster and can help standardize testing in sensory analysis. Published lexicons allow anyone working with a product to have a clearer understanding of the characteristics of that products and a clear communication tool for describing characteristics. Although there is published work relating to attributes of smoky flavor, there is not a published, detailed lexicon. The lexicon developed here is general enough to be used for all types of smoked and smoke-flavored products and can be expanded if additional terms are needed for specialized smoked products. Fourteen attributes were found: Smoky (overall), Ashy, Woody, Musty/Dusty, Musty/Earthy, Burnt, Acrid, Pungent, Petroleum-Like, Creosote/Tar, Cedar, Bitter, Metallic and Sour. This lexicon can be applied to studies of multiple types of products to help researchers and developers identify differences in the smoke flavor of specific products and describe those differences in a way that improves flavor understanding. Use of the generic term Smoke no longer need be sufficient to describe the myriad of flavors of products containing smoky notes.

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TABLES AND FIGURES

Table 1. Products used during term generation for Smoke Lexicon development

Bumble Bee Smoked Trout	Hy-Vee Fully cooked turkey bacon smoked cured
Bumble Bee Smoked Salmon	Kroger Turkey Bacon Smoked
Chicken of the Sea Smoked Salmon	Oscar Mayer Turkey bacon smoked cured
HyVee Smoke Alaska Sockeye Salmon	Farmland Naturally hickory smoked double smoked bacon
Private Selection Cracked Pepper Coho Salmon Alder Wood Smoked	Great Value Applewood Smoked Bacon
Allegro Hickory Smoke Marinade	Sterling Silver Applewood Smoked Bacon
Cookies Sweet Hickory Bar B Q Sauce	Jennie-Os Original Turkey Burgers Smoked Flavor Added
Figaro Hickory Liquid and Barbeque Marinade	Hillshire Farm Mesquite Smoked Turkey Breast
KC Masterpiece Barbecue Sauce Hickory Brown Sugar	Oscar Mayer delifresh Smoked Turkey Breast
Weber Smoky and Think Hickory BBQ Sauce	Kroger Deli Style Lean Honey Smoked Turkey Breast
Belgioioso Smoked Fresh Mozzarella (block)	Hillshire Farm Smoked Chicken Breast
Great Value Deli Style Sliced Provolone Cheese with Added Smoke Flavoring	Buddig Original Chicken Smoked
Murray's Smoked Gouda (block)	BARS Smoked Deli Style Ham
Murray's Smoked Cheddar (block)	Kroger Deli Style Lean Smoked Ham
Kroger smoke Flavor String Cheese	Hillshire Farms Smoked Ham
Figaro Mesquite Liquid Smoke and Marinade	Oscar Mayer Delifresh Smoked Ham
Curley's Mesquite Barbeque Sauce	Hormel Smoked Deli Ham
Lawry's Mesquite with Lime Juice	Hickory Pork Loin (2.5 hours)
Jack Daniel's Marinade Smoky Mesquite Liquid Marinade	Hickory Pork Loin (3 hours)
Colgin Liquid Smoke	Hickory Pork Loin (3.5 hours)
Budweiser Sweet and Smoke Barbeque Sauce	Hickory Pork Loin (4 hours)
Cookies Original Sweet and Smoky	Hickory Chicken Breast (2.5 hours)
Grill Mates Steak House Burdens Smoky Applewood	Hickory Chicken Breast (3 hours)

Sweet Baby Ray's Hickory and Brown Sugar Barbecue Sauce	Hickory Chicken Breast (3.5 hours)
Tone's Liquid Smoke	Hickory Chicken Breast (4 hours)
Hormel Bacon Lovers Naturally Wood Smoked	Hickory Potatoes (2.5 hours)
Hormel Naturally hardwood smoked applewood thick cut bacon	Hickory Potatoes (3 hours)
Hormel Naturally hardwood smoked brown sugar thick cut bacon	Hickory Potatoes (3.5 hours)
Hormel Naturally hardwood smoked pecanwood thick cut bacon	Hickory Potatoes (4 hours)
Farmland Naturally hickory smoked classic cut bacon slow smoked using real hardwood	Cherrywood Pork Loin (2.5 hours)
Kroger Fully Cooked Turkey Smoked Sausage	Cherrywood Pork Loin (3 hours)
Buddig Ham	Cherrywood Pork Loin (3.5 hours)
Smoked Cheddar (block)	Cherrywood Pork Loin (4 hours)
Jack Daniel's Honey Smokehouse Barbeque Sauce	Cherrywood Chicken Breast (2.5 hours)
Allegro Hickory Smoke Marinade	Cherrywood Chicken Breast (3 hours)
Kroger Fully Cooked Smoked Sausage	Cherrywood Chicken Breast (3.5 hours)
Kroger Fully Cooked Beef Smoked Sausage	Cherrywood Chicken Breast (4 hours)
Oscar Mayer Selects Hardwood Smoked uncured Beef Sausage	Cherrywood Potatoes (2.5 hours)
Johnsonville Smoked Brats	Cherrywood Potatoes (3 hours)
Butterball Turkey bacon smoked cured original	Cherrywood Potatoes (3.5 hours)
Great Value Turkey bacon smoked	Cherrywood Potatoes (4 hours)

Table 2. Smoke Lexicon

Smoky Overall: An aromatic that may present characteristics of sweet, brown, pungent, acrid, slightly ashy or charred/burnt.

References: Tones Liquid Smoke (2 drops in 300 ml water)= 4.0 (a)
Tones Liquid Smoke (2 drops in 200 ml water)= 5.5 (a)
Tones Liquid Smoke (2 drops in 100 ml water)= 7.0 (a)
Wood Ashes = 5.0 (a) (Wood ashes vary in their intensity depending on the type of wood and degree of burn, but can be used if the liquid smoke reference is not available.

Preparation: - Mix 2 drops of Tones Liquid Smoke with 300 ml water, serve in a large 24 ounce snifter, cover.
- Mix 2 drops of Tones Liquid Smoke with 200 ml water, serve in a large 24 ounce snifter, cover.

- Mix 2 drops of Tones Liquid Smoke with 100 ml water, serve in a large 24 ounce snifter, cover.
For wood ashes: Obtain ashes from burned wood (from fireplace or outdoor fire pit). Place ashes in 2 oz. glass jars with screw-on type lids. Fill jars approx. 1/3 full. This may be prepared several days in advance and stored at room temperature, tightly sealed. Prepare one jar for every 3 participants. These will be shared for smelling only.

Ashy: Dry, dusty, dirty smoky aromatics associated with the residual of burnt products.
Reference: Gerkens Midnight Black (BL80) cocoa Powder = 3.5(f)
Preparation: Mix ¼ tsp of cocoa powder with 100 ml of water. Serve in 1 oz. cup.

Woody: The sweet, brown, musty, dark aromatics associated with a bark of a tree.
Reference: Diamond Shelled Walnuts = 4.0 (f)
Preparation: Serve walnuts in a 1 oz. cup.

Musty/Dusty: The aromatics associated with dry closed air spaces such as attics and closets. May be dry, musty, papery, dry soil or grain.
Reference: Kretschner Wheat Germ = 5.0 (a),(f)
Preparation: Aroma- Serve 1 tablespoon wheat germ in a medium 12 ounce snifter, Cover.
Flavor- Serve wheat germ in a 1 oz cup.

Musty/Earthy: Somewhat sweet, heavy aromatics associated with decaying vegetation and damp black soil.
Reference: 50,000 ppm 1, 2, 4 Trimethoxybenzene = 4.0 (a)
4,000 ppm geosmin = 9 (a)
Miracle-Gro Potting Mix soil = 9.0 (a)
Le Nez du Café no. 1 "earthy" = 12.0 (a)
Preparation: -for the first two chemicals, dilute the chemicals in deionized water and then dip a perfumer's strip into the solutions and place in capped test tubes
-Fill a 2-ounce glass jar half full with potting soil and seal tightly with screw-on type lid.
-Place 1 drop of essence on a cotton ball in a large 24 ounce snifter. Cover.

Burnt: The dark brown carbon impression of an over-cooked or over-roasted product that can be sharp, bitter and sour.
References: Mixture of raw and burnt peanuts (3 raw:1 burnt) = 7.5 (a)
Mixture of raw and burnt peanuts (1 raw:1 burnt) = 10.0 (a)
Burnt peanuts = 13.0 (a)
Preparation**:** - for Burnt peanuts: Preheat oven to 218C. Place 1 cup of blanched peanuts in 3 liter glass pan in a single layer. Roast for 30 minutes – stir roasted peanuts every 5 minutes. Let roasted (burnt) peanut completely cool. Blend the ratio of raw and burnt peanuts specified above in a food processor until small particles are formed. Serve 15 ml in a large 24 ounce snifter.

Acrid: The sharp, pungent, bitter, acidic aromatics associated with products that are excessively roasted or browned.
References: Wright's Liquid Smoke Mesquite(1 drop in 100 ml water) = 3.0(a)
Wright's Liquid Smoke Mesquite (1 drop on cotton ball) = 9.5 (a)
Preparation: - Mix 1 drop of Wright's Liquid Smoke Mesquite with 100 ml water, serve in a large 24 ounce snifter, cover.

-Place 1 drop of liquid smoke on a cotton ball in a large 24 ounce snifter. Cover.

Pungent: The sharp physically penetrating sensation in the nasal cavity.
Reference: Reese Horseradish and Hiland sour cream = 2.5 (a)
Heinz White Vinegar = 8.0 (f)
S&B Wasabi paste in water = 10.0 (a)
Preparation: -Mix 1 gram of sour cream with 0.68 grams of horseradish. Serve in a medium snifter. Cover.
- Mix 1 part vinegar with 8 parts water. Serve in a 1 oz cup
-Mix 1 gram of wasabi paste in 50 ml. water. Serve in a medium 12 ounce snifter. Cover.

Petroleum-like: A specific chemical aromatic associated with crude oil and its refined products that have heavy oil characteristics
Reference: Vaseline Petroleum Jelly: 3.0 (a)
Motor oil, Castrol HD Optimum viscosity = 7.5 (a)
Preparation: -Place a teaspoon of jelly in a medium 12 ounce covered snifter.
- Place 1 drop of motor oil on a cotton ball in a medium 12 ounce snifter. Cover.

Creosote/Tar: A pungent chemical aromatic associated with unrefined crude oil products.
References: Tar = 12.0
Preparation: Put 1 tsp of tar into a 60 ml glass jar and seal tightly with a screw-on type lid.

Cedar: A slightly sweet, dark, and musty aromatic associated with trees such as cedar.
Reference: Hartz Natural Red Cedar Small Animal Bedding & Litter = 6.0 (a)
Aldrich Cedarwood oil, Virginia = 9.5 (a)
Preparation: -Place 5 grams of red cedar shaving in a medium 12 ounce snifter. Cover.
-Place 1 drop of Cedarwood oil on a cotton ball in a large 24 ounce Snifter. Cover.

Bitter: The fundamental taste factor associated with a caffeine solution.
Reference: 0.01% Caffeine Solution = 2.0
0.02% Caffeine Solution = 3.5
0.035 % Caffeine Solution = 5.0
0.05% Caffeine solution = 6.5

Metallic: An aromatic and mouthfeel associated with tin cans or aluminum foil.
Reference: 0.10% Potassium Chloride Solution = 1.5 (f)

Sour: The fundamental taste factor associated with a citric acid solution.
Reference: 0.015% Citric Acid Solution = 1.5
0.05% Citric Acid Solution = 3.5

(a) = aromatic that is smelled only and the intensity is translated to the flavor in the mouth for the purposes of intensity evaluation.
(f) = flavor that is tasted and used for the purposes of intensity evaluations

Table 3. Eigenvectors from PCA of lexicon validation

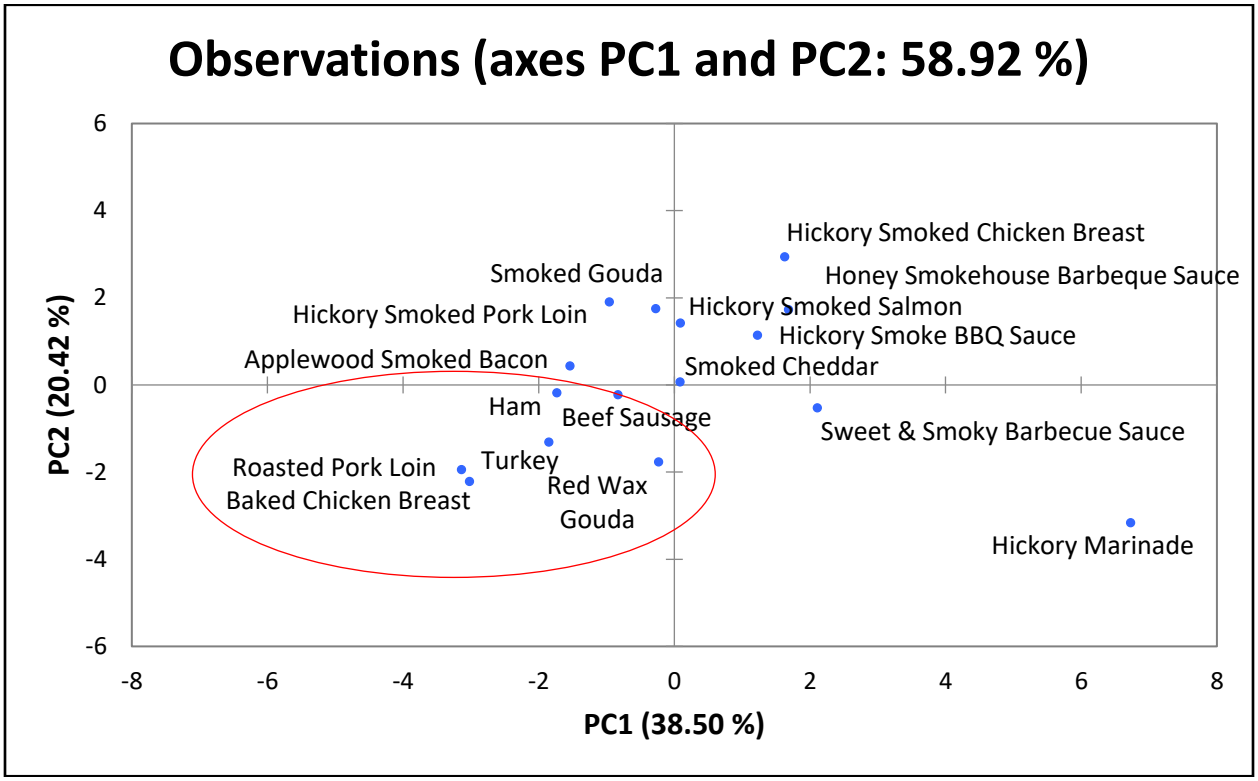
Eigenvectors				
Attribute	**PC1**	**PC2**	**PC3**	**PC4**
Smoky	0.133744	**0.376281**	0.192615	0.188221
Ashy	**0.306962**	**0.328767**	0.120942	-0.08389
Woody	0.224889	**0.402062**	0.205225	0.123446
Musty/Dusty	0.095717	**0.4968**	-0.03735	-0.15151
Musty/Earthy	0.067716	-0.15932	-0.05985	**0.660541**
Burnt	**0.322428**	-0.28612	0.294049	-0.15532
Acrid	**0.315069**	-0.0719	0.368692	-0.21251
Pungent	**0.313603**	-0.13281	-0.35047	0.177985
Petroleum-Like	0.102975	0.233039	0.12022	**0.457391**
Creosote/Tar	**0.309963**	-0.24415	0.081881	0.271616
Cedar	**0.322428**	-0.28612	0.294049	-0.15532
Bitter	**0.359005**	0.02156	-0.20127	-0.04185
Metallic	0.247849	0.117308	**-0.49646**	-0.27024
Sour	**0.347892**	-0.04247	**-0.40169**	0.013217

*Major Drivers of each PC in bold

Table 4. Correlation Matrix of Validation Data

Variables	Smoky	Ashy	Woody	Musty/ Dusty	Musty/ Earthy	Burnt	Acrid	Pungent	Petroleum-Like	Creosote/ Tar	Cedar	Bitter	Metallic	Sour
Smoky	**1**	0.605	0.654	0.415	0.061	-0.012	0.101	0.046	0.214	0.052	-0.012	0.270	0.064	0.060
Ashy	0.605	**1**	0.769	0.561	-0.104	0.339	0.491	0.264	0.294	0.298	0.339	0.519	0.479	0.470
Woody	0.654	0.769	**1**	0.635	0.070	0.168	0.327	0.146	0.396	0.148	0.168	0.285	0.265	0.249
Musty/ Dusty	0.415	0.561	0.635	**1**	-0.301	-0.197	0.106	0.009	0.317	-0.288	-0.197	0.259	0.278	0.160
Musty/ Earthy	0.061	-0.104	0.070	-0.301	**1**	0.121	-0.102	0.252	0.132	0.285	0.121	0.173	-0.189	0.264
Burnt	-0.012	0.339	0.168	-0.197	0.121	**1**	0.786	0.442	-0.124	0.683	1.000	0.511	0.138	0.462
Acrid	0.101	0.491	0.327	0.106	-0.102	0.786	**1**	0.262	0.231	0.504	0.786	0.561	0.200	0.352
Pungent	0.046	0.264	0.146	0.009	0.252	0.442	0.262	**1**	0.142	0.736	0.442	0.612	0.551	0.783
Petroleum-Like	0.214	0.294	0.396	0.317	0.132	-0.124	0.231	0.142	**1**	0.303	-0.124	0.150	-0.017	0.069
Creosote/ Tar	0.052	0.298	0.148	-0.288	0.285	0.683	0.504	0.736	0.303	**1**	0.683	0.433	0.203	0.489
Cedar	-0.012	0.339	0.168	-0.197	0.121	1.000	0.786	0.442	-0.124	0.683	**1**	0.511	0.138	0.462
Bitter	0.270	0.519	0.285	0.259	0.173	0.511	0.561	0.612	0.150	0.433	0.511	**1**	0.606	0.811
Metallic	0.064	0.479	0.265	0.278	-0.189	0.138	0.200	0.551	-0.017	0.203	0.138	0.606	**1**	0.734
Sour	0.060	0.470	0.249	0.160	0.264	0.462	0.352	0.783	0.069	0.489	0.462	0.811	0.734	**1**

Figure 1. Map of Observations Based on PC1 and PC2 from Validation



*Red circle is around all unsmoked samples, which clustered on the negative side of both PC1 and PC2

Chapter 3 - Differences between products smoked using an at-home smoker and market products

ABSTRACT

Smoking is a cooking technique that is used to impart desirable sensory characteristics to foods. There are many methods used to impart this smoky flavor and due to health, environmental and economic concerns, many producers use non-traditional methods while hobbyists thrive on the traditional methods. This study measured, using sensory descriptive analysis, if products smoked in a manner that someone would at home has a different smoky flavor profile than products found on the market. A range of products were evaluated by a highly trained descriptive sensory panel. Only the flavor characteristics associated with the smoke flavor were evaluated. Using principal component analysis, cluster analysis and analysis of variance, it was found that the market products were significantly different than the products smoked using an at-home smoker. The market products were significantly more Sour and less Smoky, Ashy, Woody, Musty/Dusty and Acrid. The current market trends show that consumers want their foods to be more authentic, so using this information, product developers can know what types of flavors their products should be to taste more authentically smoked.

INTRODUCTION

Smoking can be utilized to cook and impart a desired flavor onto many types of products. The smoke is also concentrated into liquid smoke and artificially made flavors can be created to add smoke flavor both at home and in large processing environments.

Smoky, which is commonly used as a single attribute in descriptive analysis (Smiecinska and Chwastowska 2006; Bárcenas et al. 2001), can be broken down into more specific attributes such as artificial (Portella et al. 2011), bitter (Portella et al. 2011; Almli and Hersleth 2013), tart (Smiecinska and Chwastowska 2006), vegetal and herb (Séménou et al. 2007, Midelet-Bourdin et al. 2008), rubber (Midelet-Bourdin et al. 2008; Brillet et al. 2005), wood fire (Mørkøre et al. 2001; Cardinal et al. 2001; Séménou et al. 2007) and pungent (Bárcenas et al. 2001).

Several factors can affect the profile of the smoky flavor. There are many different methods that are used to smoke products, such as traditional wood fires, electric smokers and counter-top smokers. Products can also gain smoky flavors from smoke concentrates (liquid smoke) and artificial flavorings. Many studies have proven that the smoke flavor comes from an array of volatile compounds (Chambers et al. 1998; Kostyra and Barylko-Pikielna 2005; Fujimaki et al. 1974) and that many of those compounds can not only be present or not, but also at different levels and the flavor will still be considered smoky (Guillen and Manzanos 2002).

The process of smoking meats adds many compounds to the final product, many of which are thought to be dangerous to the health of humans (IARC 2010). Due to this health concern, many producers are using liquid smoke to add smoky characteristics to their products. Liquid smoke is a water-soluble solution created by condensing smoke and because there is no standard of identity for liquid smoke commercial products can vary widely. Liquid smoke can be desirable because the refining process removes polycyclic aromatic hydrocarbons, which are considered to be carcinogenic and the end flavor intensities and color can be adjusted (Cadwallader 2007; Varlet et al. 2010). The use of liquid smoke has benefits such as lower environmental pollution, cost and the products are more uniform (Gonulalan et al. 2003). Due to

these benefits, producers may choose to use these products over using traditional smoking methods.

Many factors affect the smoke flavor of a product and most of the time producers will not use the same methods that are used at home by hobbyists or by restaurants that specialize in smoked foods. According to research by McCluskey, authenticity is becoming a more important factor when consumers buy their foods (2015). With this trend, producers will want to create products with a more "authentic" taste. The objective of this study was to see if and how products on the market are significantly different than products made using a method a hobbyist would use.

MATERIALS AND METHODS

Samples

Twenty-eight samples were used for this experiment (Table 5). Eight were smoked in-house and the other 20 were bought in a national chain grocery store (Dillon's, HyVee or Walmart). There were 9 categories of products: fish, sausage, beef, turkey, bacon, pork, chicken, lunch meat and cheese. Some of the products overlapped categories, such as the lunch meat. There was one beef, turkey, chicken and ham type of lunch meat, three of which fall directly into another category and one (ham) that is closely related to the pork, bacon and sausage categories. The sausage category includes 2 pork sausages, 1 beef and 1 turkey sausage.

Eight of the products were smoked in house. All of the products were smoked in an electric smoker (30 lb Digital Country Style Smoker, Model 40903, The Sausage Maker Inc, Buffalo, NY, USA) using hickory wood (Cowboy Brand, Cowboy Charcoal, LLC, Albany, KY, USA). The wood used was small wood chips and were soaked in deionized water before being placed on the heat source. Pork loins, chicken breasts, turkey breasts and beef were all used and

there was one sample of each smoked for 2 hours and one for 4 hours. The pork loins were in the form of 1 inch pork chops, the chicken and turkey breasts were an entire breast and the beef was in 1 inch steaks. The wood chips were replaced after 2 hours so that there was constantly smoked being produced. The smoker was set at 93 °C.

All products were served in capped 3.25 ounce cups (Solo, P325N, Dart, Mason, Michigan, USA), in bite-size pieces and at the temperatures that they are typically eaten, such as >60 °C for hot products. The products that were smoked in house were heated in a conventional oven until they reached the safe internal temperature set by the USDA (74 °C for poultry and 63 °C for pork and beef). The deli meats and cheese were served chilled, being taken out of the refrigerator directly before evaluation. The smoked fish, which were all canned, were served at room temperature and taken out of the can directly before evaluation. The sausage and bacon were both prepared according to the package instructions and served at 63 °C. All products that were served hot were kept on a heated brick so that they stayed warm through the entire evaluation. Every product also had a 4-digit blinding code so that the panelists, which is all the information the panelists were given about the product.

Panelists

Six highly trained and experienced panelists were used in this study. Each panelist had and minimum of 120 hours of training at the Kansas State University Sensory Analysis Center and have had over 1000 hours of experience evaluating food and beverage products. All panelists also participated in similar studies involving smoke flavor.

In order for the panelists to prepare for this project they had one 1.5 hour orientation session. In this session they reviewed all attributes, their definitions and references. They also

practiced the evaluation method. One orientation session was sufficient due to the fact that these panelists have previously worked with similar products and the same list of attributes.

Evaluation

After the orientation session, there were 7 1.5 hour evaluation sessions. Four products were evaluated in each session, leaving the panelists a minimum of 15 minutes of evaluation and a 5 minute cleansing period. The products were served to the panelists monadically. Unsalted crackers, whole milk and deionized water were used as palate cleansers between the samples.

The consensus method was utilized for the evaluation of all the products. The panelists first evaluated the product individually and then discussed their results. The discussion was led by the panel leader, who was a member of the panel, and the panelists came to a consensus to which intensity they should give for each attribute. This leads to one flavor profile of each product that was evaluated.

The panelists used an earlier developed lexicon for smoke flavor (Jaffe et al. 2017). The attributes refer to the smoke flavor only and not to any flavors that come from the raw products. The evaluation was only on the smoke profile of the products.

Data Analysis

The data was analyzed using XLStat (Version 2015.3.01, Addinsoft, New York, New York, USA). First a principal component analysis was carried out and a biplot was produced. This allows for an easy visualization of the data that shows how related products are to each other which attributes may differentiate that product from a different one. This can also give a hint to possible clusters of products that are similar. The second type of analysis carried out was hierarchal cluster analysis. This groups the products in the amount of classes (clusters) that can describe the biggest and most notable differences and similarities between the products.

An analysis of variance was run to compare the market products to the products smoked with an at-home smoker to see if any of the attributes were significantly different between the two groups. A 95% confidence level was used with the source of variance being the type of product (market or at-home).

Any attributes that were only found in 1 or 2 products, or were not found in any products were taken out of the data set for analysis since those attributes would have driven the entire analysis and the differences between attributes in all or most products would not have as much weight. Three attributes were not used while analyzing the data: Burnt, Pungent and Cedar. Only two products had intensities for Burnt and Cedar and no products had intensities of Pungent.

RESULTS AND DISCUSSION

A principal component analysis (PCA) was run on the entire data set (Figure 2). All of the products that were smoked using an at-home smoker are on the right side of the graph and all but two market products are on the left. The sockeye lox and atlantic lox (market products) are both on the right side of the graph, but are close to the origin and when only looking in the direction of PC1, they do not overlap with the products that were smoked using an at-home smoker.

Principal component 1, which was what divides the products between the market and products that were smoked using an at-home smoker, was mostly driven by Smoky, Ashy, Woody, Musty/Dusty, Musty/Earthy and Acrid in the positive direction and Sour and Petroleum-Like in the negative direction. The definition for Petroleum-Like includes “chemical aromatic”, so that attribute being very characteristic of the market products means that many of those products were probably made smoky by the use of liquid smoke or flavorings.

In order to confirm what clusters were seen in the biplot, hierarchal cluster analysis (CA) was used. Figure 3 shows the dendogram on the entire data set. The samples were broken into 3 classes. Class 1 includes all of the market products, except the Atlantic Lox and is most strongly categorized by the petroleum-like attribute.

Class 2 is a single variable class, which is the Atlantic Lox and is categorized by its Creosote/Tar note. The Atlantic Lox had a significantly higher Creosote/Tar intensity (6.5 vs 1.5-2.5) which pulled it far away from all other products. Class 3 is categorized by its high smoky, ashy and woody notes and included only the products that were smoked using an at-home smoker.

Because the cluster analysis revealed that the market products are different than the products that were smoked using an at-home smoker, an analysis of variance was run comparing all the products that were smoked using an at-home smoker to the market products. The ANOVA revealed that there were significant differences between the two groups in the attributes Smoky, Ashy, Woody, Musty/Dusty, Acrid and Sour. The market products had significantly more intense Sour notes while the products that were smoked using an at-home smoker had significantly higher Smoky, Ashy, Woody, Musty/Dusty and Acrid notes.

The only source of variance that the ANOVA took into account was whether the product was smoked using an at-home smoker or was bought on the market. In both of those categories there were multiple types of products such as different types of meats a cheese. Because there was so much variability within the groups, the number of significant differences found between the groups was surprising but leads to the strong result that market products are significantly different than products smoked using an at-home smoker.

The market products had significantly higher intensities in Sour and the PCA has a lot of the market products associated with Petroleum-Like. This is probably due to the fact that the food producers are using liquid smoke, flavorings and other chemicals in their products. On the other hand, the products smoked with an at-home smoker were significantly higher in Ashy, Woody and Musty/Dusty which are associated with a more "pure" smoked flavor.

CONCLUSION

This study revealed that there are significant differences between smoked products found on the market and products that people are smoking at home. Many market products make claims related to their smoky flavor and many times the methods to create that smoky flavor were through the use of liquid smoke or flavors. According to this study, these methods do not lead to similar results as smoking using more traditional methods does. Products that were smoked using an at-home smoker have a more "pure" smoke flavor, including attributes such as Ashy, Woody and Musty/Dusty. Market products have significantly higher sour notes and higher Petroleum-Like notes, which most likely stem from the high chemical nature of liquid smoke and flavorings.

Product developers can take this information to create smoked products that have a more authentic taste. In order to further this study, the volatiles found in smoke could be studied to see which compounds give off the flavors associated with attributes that are in more products that were smoked using an at-home smoker. This could lead to flavorings that give a more authentic taste while still keeping the health, environmental and economic concerns at a minimum.

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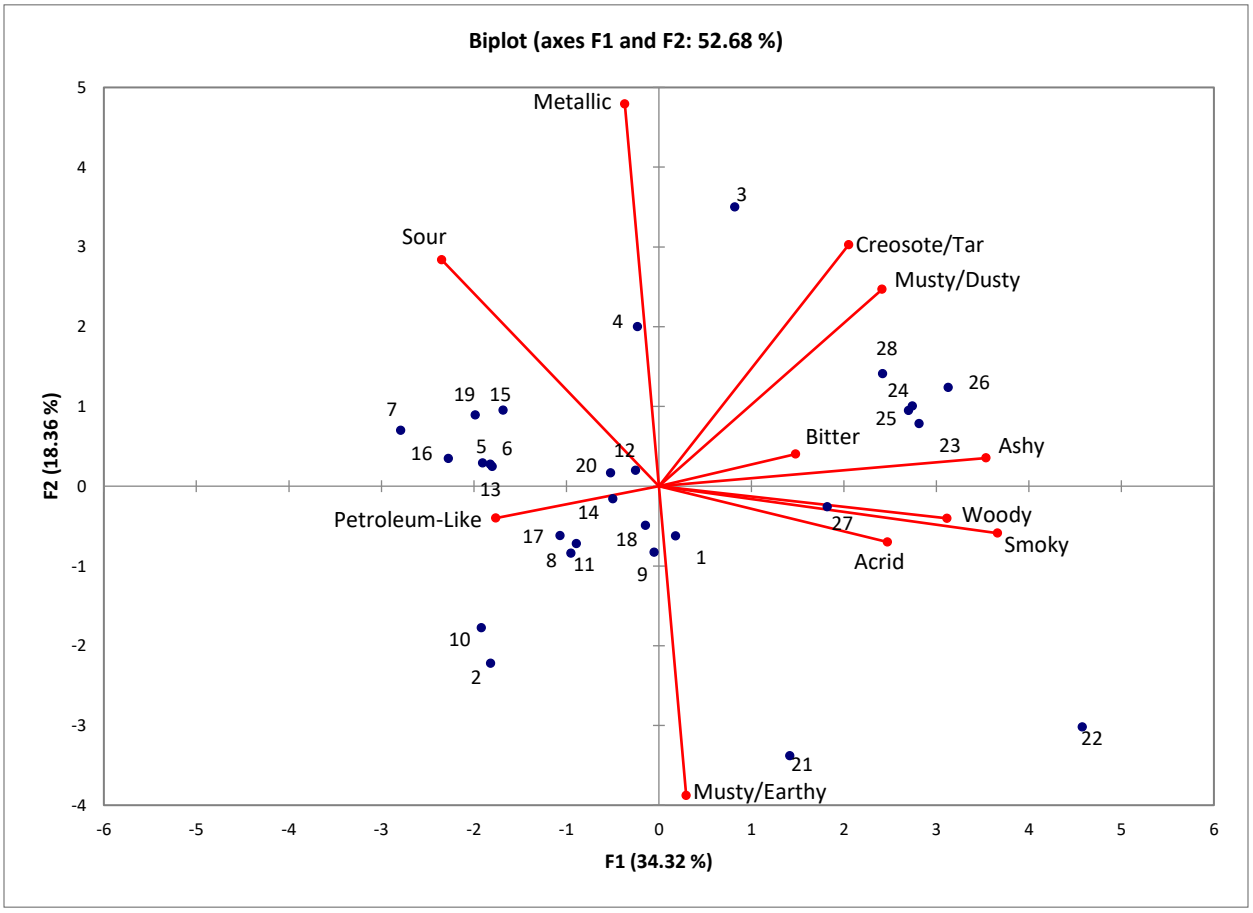
TABLES AND FIGURES

Table 5. List of all products evaluated

Number	Product
1	Private Selection Sockeye Lox
2	Bumble Bee Smoked Trout
3	Private Selection Atlantic Lox
4	Bumble Bee Smoked Salmon
5	Hillshire Farm Smoked Sausage
6	Hillshire Farm Beef Smoked Sausage
7	Hillshire Farm Turkey Smoked Sausage
8	Kroger Smoked Sausage
9	Smithfield Thick Cut Bacon
10	Private Selection Center Cut Bacon
11	Hormel Black Label Bacon
12	Farmland Applewood Smoked Bacon
13	Buddig Beef
14	Oscar Mayer Deli Fresh Smoked Turkey Breast
15	Hillshire Farm Smoked Chicken Breast
16	Kroger Deli Thin Sliced Smoked Ham
17	Murray's Smoked Gouda
18	Murray's Smoked Cheddar
19	Boar's Head Smoked Gouda
20	Boar's Head HIckory Smoked Gruyere
21	In-House Smoked Beef - 2 hrs
22	In-House Smoked Beef - 4 hrs
23	In-House Smoked Turkey - 2 Hours
24	In-House Smoked Turkey - 4 Hours
25	In-House Smoked Pork - 2 hours
26	In-House Smoked Pork - 4 hours
27	In-House Smoked Chicken - 2 hours
28	In-House Smoked Chicken - 4 hours

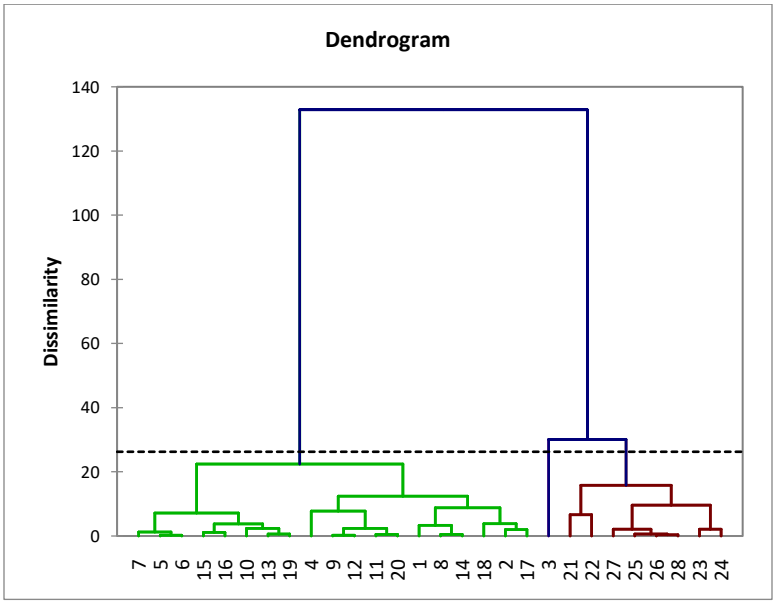
*Each product is referred to by their corresponding number in all following figures. Numbers 1-20 are Market Products and numbers 21-28 are products smoked in an at-home smoker

Figure 2. Biplot of PC1 and PC2 from PCA of evaluation data of all products



*See Table 5 for the corresponding product for each number

Figure 3. Dendogram of all products based on hierarchal cluster analysis



*See Table 5 for the corresponding product for each number

Chapter 4 - Effect of Wood used for Smoking on Smoke Flavor in Pork

ABSTRACT

Smoking of food is a cooking method used for thousands of years, first as a preservation method and now, in part, for its characteristic and desirable sensory properties. Many types of woods are used to smoke products, such as hickory, mesquite, apple and cherry. The objective of this study was to determine if the flavor of the smokiness of products was different depending on the type of wood used. Six highly trained descriptive panelists rated the intensities of 14 flavor attributes which were all related to the smoke flavor of the product, ignoring the flavor attributes from the raw product (pork). The pork samples were smoked by the researcher with a commercial home use smoker. The four types of woods listed above were used and the products were smoked for 1, 2 and 4 hours. The flavor profiles of the smoke flavor was similar between the types of woods although as the length of time in the smoker increased and the intensities of most attributes rose, the differences among products smoked with different woods became more pronounced. Apple wood smoked products had higher intensities for Overall Smoky, Ashy, Burnt, Pungent, Petroleum-Like, Creosote/Tar and Cedar, while cherry wood smoked products had lower intensities for all attributes. Hickory and Mesquite smoked products were not significantly different from each other and typically scored between the other two woods.

INTRODUCTION

Smoking has been used as a cooking method since ancient times when it was discovered that it was effective as a preservation method. Today, because new preservation methods have

been discovered, smoking is used for the distinctive flavor it imparts on food (Chambers et al.1998).

Many restaurants that specialize in smoked foods use a number of claims to suggest that their product is 'better' than some other unnamed product, claims that are not based on established advertising claims guidelines such as ASTM (ASTM E1958-16a) but rather on awards won, testimonials, or such criteria as the amount of time the product is smoked or the type of wood used. Commercially prepared and sold supermarket products also distinguish their products using type of wood as a differentiating characteristics. For example, bacon is described as 'applewood' smoked or barbeque sauce is labeled hickory or mesquite.

Many types of woods are used, such as oak, apple, cherry, hickory, mesquite and pecan. The smoke flavor from different types of woods have been studied for their consumer desirability and found that broad-leaved trees are superior to needle-leaved trees (Tilgner 1958). However, the woods that are commonly used for smoking were all in the highest liking group and not significantly different from each other.

Many studies using gas chromatography have shown differences in aromatic compounds among products smoked using different types of woods (Moreno-Escamilla 2015; Guillen and Ibargoita 1999; Guillen & Manzanos 1996; Serot et al 2004). Similarly, the flavor chemicals in liquid smoke coming from different woods have also been studied leading to similar results (Fujimaki 1974). These differences come not only from the mixture of chemicals in the final product but also from the proportion of the different compounds (Guillen and Manzanos 2002). These experiments focused on the chemical composition of the final products and not the sensory aspects. The association between the chemical composition and sensory aroma and flavor may be

difficult to identify (Chambers and Koppel 2013), thus these studies give little knowledge of the actual flavor of the products.

There is little research focusing on the flavor of smoked products, and less using descriptive analysis to study it. That may be because the typical sensory description of smokey flavor in food is simply 'smoky', smokey', or 'smokiness' (Gaudette and Pietrasik 2017; Kyraleou et al. 2015; Imamura 2016; Chambers et al. 2016; Pujchakarn 2016). Chambers et al., (1997) studied the odor of chemicals that potentially were associated with smokey flavor and identified as few odor notes that represented different qualities of smoky odor, but little follow-up work appears to have been done. Jaffe et al., (2017), published a lexicon evaluating the flavor of smoked food products that can be used to better evaluate products. That lexicon was more encompassing in its study of smoky food products and identified 14 attributes that could be used to describe differences in smoky flavors.

No studies were found that characterized the effects on sensory characteristics of smoking meat with various woods. Thus, the objective of this study was to determine if smoking a meat product, pork, with different types of wood for different lengths of time affects the smoky flavor profile of the final project. Only the flavor attributes that come from the smoking process were examined in this study.

MATERIALS AND METHODS

Pork Samples

Because the focus of this study was on the specific smoke flavor from different woods and not on the base product flavor, only one intact meat sample, center cut pork loin chops, were used. The study was designed as a 4 X 3 factorial (woods X smoke time) with 3 replications (separate smoked batches).

Center cut pork loin chops (HyVee, West Des Moines, IA, USA) were used because they are reasonably consistent in quality and fat content, can be cut to a consistent size and shape, and are small enough to get a reasonable level of smoke flavor and reach a proper cooked temperature in a relatively short period of time ensuring no food safety issues. The use of only one reasonably consistent meat source lowered the variance in samples caused by raw meat material, which could enhance differences noted specifically related to the effect of wood.

The full pork loins were cut into 1 inch pork chops, the excess fat on the outsides was cut off and the meat was cut into a similar size and shape with only the loin muscle used. After smoking (procedure outlined below), the samples were packaged in vacuum-sealed bags and kept in a refrigerator until the day they were evaluated (maximum 7 days). Before serving, the samples were heated in an oven set to 178 °C until they reached an internal temperature of 63 °C. The samples were then cut into 1.25cm cubes. Each piece had one side that had direct contact with the smoke.

Wood Samples

Four types of wood were used in this study: Hickory, Mesquite, Applewood and Cherrywood (Cowboy Brand, Cowboy Charcoal, LLC, Albany, KY, USA). The wood was in the form of small wood chips, ranging from about a ½ cm to 3 cm. All wood was sold with the intent that they are used in an electric smoker (30 lb Digital Country Style Smoker, Model 40903, The Sausage Maker Inc, Buffalo, NY, USA). All samples were purchased from the same large online retailer.

Four cups of wood chips were soaked in two cups of water for 10 minutes. The water was then drained out and the wet chips were put into a shallow pan of the smoker. With the chips

being wet, both smoke and vapor are created when the smoker's heat is on, this shortens the treatment time and creates a better smoke yield (Ellis 2001).

Smoking

The samples were smoked in an electric smoker set at 93 °C. The shallow pan with the four cups of wood chips was placed on the electric burner at the bottom of the smoker. A metal dispersing hood was placed about 3 inches above the pan to ensure that the smoke was more evenly distributed in the smoker and drain fat drippings from the meat away from the heat source to keep fat from burning and causing both as safety hazard and smoky flavors unrelated to the wood to alter results. All pork samples were placed on the same metal grid about two inches away from each other. This allowed them to be at the same distance from the heat source.

One sample was taken out of the smoker after 1 hour, another sample after 2 hours and another after 4 hours. Three smoking trials or batches were done for each of the four types of wood, resulting in three replications of each wood X smoke time combination. In total there was 36 samples of smoked pork loin (4 woods X 3 smoke times X 3 replications).

The products were being smoked the same two weeks the orientation sessions and evaluation was happening, starting 2 days beforehand. A schedule was created so that there was always samples that came from different types of woods and were smoked for different lengths of time available for evaluation on any given day. No sample was evaluated the same day it was smoked. Smoked products were cooled to room temperature after being taken out of the smoker, then sealed in a vacuum sealed bag and stored in a refrigerator until evaluation. No sample was in the refrigerator more than 7 days.

Panelists and Sensory Procedure

Six highly trained panelists participated in this study. All panelists were trained at the Kansas State University Center for Sensory Analysis and Consumer Behavior for a minimum of 120 hours and had experience evaluating the flavors of many food and beverage products.

Four orientation sessions (1.5 hours each) were conducted with the primary objective to have the panelists become familiar with the lexicon, references, ballot and evaluation process that was being used. The lexicon that was used was previously developed and used for other research related to smoky flavor (Jaffe et al., 2017). The first two sessions focused on the 14 attributes, their definitions and references. The panel leader led the group in discussion and making sure that all panelists understood the lexicon and the exact flavors they would be looking for during evaluation. The second two sessions focused on practice evaluation. The panelists first practiced by tasting the products and coming to a consensus on the scores. This helps the panelists find where they differ in scores so that they can discuss that attribute and, if necessary, create a specific method to evaluate that attribute. Once all of the panelists understood how to exactly evaluate the products, they practiced evaluating individually.

After the orientation session, 6 evaluation sessions took place. Six samples were evaluated at each 1.5-hour session. This allowed for 15 minutes of evaluation per sample. Because the panelists had practiced the evaluation, and the lexicon only had 14 attributes, 15 minutes was sufficient for each sample to be evaluated and to neutralize the palettes of the panelists between samples. Whole milk and deionized water was used to help the panelists cleanse their palettes and breathing through warm, wet washcloths was used to refresh the panelists' nasal passages because most of the references were aromatic compounds rather than flavors they could taste.

The samples were presented in 3.25 oz cups (Solo, P325N, Dart, Mason, Michigan, USA) with lids, and labeled with a random 3-digit code. The panelists evaluated the products individually. For every attribute, they assigned an intensity. The scale used was 0 to 15 with 0.5 increments. For consistency, the panelists put one 1.25cm cube of pork on their tongue, smoked side down. The smoked side is the side that was on the outside of the meat while it was in the smoker, and could easily be distinguished due to a darker color. The sample was then chewed down and expectorated. During mastication some swallowing did occur so that the retronasal aromatics were still included.

Data Analysis

Spider plots were created using the averaged data to visualize the data. The graphs were made so that the types of woods could be compared at the same time points. One graph was made for the products smoked for 1 hour with the observations being the types of wood. Other spider plots were made so that each graph was for a different type of wood and the observations were the lengths of time.

XLStat (Version 2015.3.01, Addinsoft, New York, New York, USA) was used to conduct statistical analysis of the data. Two-way analysis of variance (ANOVA) with Fisher's LSD was used to test for significant differences between the woods. The individual panelists were considered as random effects. A 95% confidence level was used. Time and type of wood were used as the sources of variation.

Principal component analysis (PCA) was also run using XLStat. A biplot was created to easily visualize which samples are most characterized by what attributes. PCA was run on the data set as a whole and one each time point individually to see the effects of the woods independently of the time of the product was smoked.

RESULTS AND DISCUSSION

The spider plots of the averaged data for each time point can be seen in Figure 4. The products smoked for 1 hour all had low intensities in Musty/Earthy, Pungent, Cedar and Metallic. The largest difference between the types of woods was for Smoky, which had an almost 1.5 intensity difference. All of the product had similar flavor profiles, however the products smoked with Cherrywood had lower intensities for most attributes.

The products smoked for 2 hours had similar flavor profiles to the products smoked for 1 hour. Musty/Earthy, Pungent and Cedar were still all below an intensity of 1 (out of 15) and only the Hickory smoked products had a Metallic intensity above 1. The Cherrywood smoked product still consistently had lower intensities and Hickory consistently had higher intensities.

Differences between products smoked with different types of wood were much more visible when looking at the products smoked for 4 hours. Musty/Earthy still had very low intensities across all samples, but Pungent, Cedar and Metallic were all detectable. The largest differences between samples were for the attributes Smoky, Burnt, Acrid and Creosote/Tar. Applewood smoked products have consistently higher intensities while Cherrywood smoke products have lower, which it had at the 1, 2 and 4 hour time points.

When looking at the 3 times points for the samples smoked with hickory wood (Figure 5), almost all attributes go up in intensity over time. There is little to no Musty/Earthy and Cedar for any of the time points and the sample smoked for 2 hours was higher in Creosote/Tar than the sample smoked for 4 hours. There are a couple attributes that are the same, or close, between two time points, but in general, the intensities go up with time.

The spider plots for the Mesquite, Cherrywood and Applewood samples follow the same trend as the Hickory. However, the Cherrywood and Applewood graphs show that the product smoked for 4 hours has much higher intensities than the products smoked for 1 and 2 hours.

Two-way ANOVA, looked at the effect of time, wood and the interaction between the time and wood. All of the attributes except Musty/Dusty and Metallic showed significant differences. There were many significant differences between samples smoked for different lengths of time and half of the attributes had significant differences between the woods smoked for 4 hours. When looking at the samples smoked at 1 and 2 hours there were only significant differences for the Smoky and Ashy attributes.

When looking at the Smoky attribute, the sample that was smoked with Applewood for 4 hours was significantly higher than the rest of the samples. The samples smoked for 4 hours have the highest intensities, except Hickory 2 is higher than Cherry 4 (although not significantly). The samples smoked for 1 and 2 hours have more significant differences between the woods as they do the times. Cherry 1 and 2 and Mesquite 1 are significantly less Smoky than the rest of the samples.

Ashy, Woody, Burnt, Acrid, Pungent, Petroleum-Like, Creosote/Tar, Bitter and Sour all had similar results as Smoky. The most notable differences are that Cherry 4 had a significantly lower Pungent and Petroleum-Like notes and Mesquite 1 had a notably high Creosote/Tar note.

Hickory 1 was the only sample that had a significant difference for the Musty/Earthy attribute (on the high side). Apple 4 had a significantly higher Cedar note than the rest of the samples while Hickory 1 had a significantly lower intensity (0) than the highest samples.

For most of the attributes, there weren't many significant differences between the samples smoked for 1 and 2 hours. The exceptions are Smoky, Burnt, Acrid, Pungent, Bitter and

Sour. For all of those attributes, there was at least one sample from the 2 hour time point that was significantly higher than at least one sample from the 1 hour time point. In most cases, Hickory 2 (which regularly has intensities closer to the 4 hour samples) was significantly higher than Cherry 1 (which has consistently low intensities). The only exception is Pungent.

The other piece of data analysis were PCA in order to see if products smoked with a certain type of wood were more driven by certain attributes. A PCA was first run on the entire set of averaged values (all wood types and hours smoked), but little information could be gathered from that analysis. The biplot has all of the attributes going strongly to the right of the graph (Figure 6). This is because the time spent in the smoker is a factor, and almost all intensities for all attributes for all products went up over time. The first principal component (PC) explained 77.84% of the variance and no particular attributes are strongly driving that PC. There is also a general trend that the longer a product was smoked for, the more to the right that product is on the biplot. This can imply that PC1 was driven by the overall flavor intensity of the product. What can be seen from this biplot is that some products, even though they were smoked for a longer time, are similar to products from different woods smoked for shorter times. For example, the Cherrywood product that was smoked for 2 hours was similar to the products from the other woods that were smoked for 1 hour. Also, the Hickory product that was smoked for 2 hours is similar to the products smoked for 4 hours.

Because of the little information gathered from the PCA of the entire data set, the data was split up by time so that the effects of the wood can be observed. The biplots of these PCAs can be seen in Figures 7, 8 and 9. They all have some similarities in that most of the attributes are strongly towards the right of the graph, although they are more spread out than they were on

the biplot of the entire data set. Also, the first PC for all of the analyses explain a large amount of the variance of the data set.

The biplot for the products smoked for 1 hour has the Mesquite, Hickory and Applewood products all on the right side of the graph and the Cherrywood product is by itself on the left side. The Hickory and Applewood products are close to each other, so it can be assumed that they are similar. The Mesquite product can be differentiated from the other products by its Petroleum-Like and Creosote/Tar intensities, the Applewood product is differentiated by its Pungency and the Hickory product is differentiated by its Musty/Earthy intensity. The Cherrywood product, which generally had lower intensities in all attributes, is characterized by that.

The biplot for the products smoked for 2 hours differentiates the products by mostly 1 PC, which explains 79.62% of the variance. PC1 is not driven by any particular attribute, but does have sour going in the opposite direction of all the attributes. From this, we can imply that PC1 is mostly driven by the overall intensity. The Hickory product is by itself on the right side of the graph meaning that it is much higher in its overall intensity of its smoky flavor. The Cherrywood product is furthest to the left, which is supported by the fact that is has the lowest intensity for almost all attributes. The Applewood and Mesquite products are right on top of one another when just looking at the X-axis, and is differentiated by Mesquite's Sour intensity which is the major driver of PC2.

The last biplot is for the products smoked for 4 hours. There were the most amount of significant differences between these products, when doing the ANOVA, and this is supported by the spread of the products on this biplot. Each product is in a different quadrant. The Hickory product is in quadrant 1, which includes the attributes Musty/Dusty, Metallic, Acrid, Woody,

Musty/Earthy and Pungent. The observation is not particularly close to any of the attributes and is the closest product to the origin of the graph. Quadrant 2 includes the Cherrywood product and the attribute Sour. This is similar to the biplot for the products smoked for 2 hours. Quadrant 3 includes no attributes, but has the Mesquite product. Quadrant 4 has the Applewood product and the attributes Smoky, Ashy, Bitter, Creosote/Tar, Petroleum-Like and Cedar. The Applewood observation is also far to the right of the graph, which is supported by the fact that it has a higher intensity for almost all attributes.

When looking at the results comparing the smoking times to one another, there is very little that is surprising. For all woods, almost every attribute went up over time, which is expected since the products are in contact with the smoke longer. There are some differences with how the flavor changes depending on the type of wood. Hickory had quicker effects on the flavor, which can be seen since at hour 2 it had most of the highest intensities.

The two extreme woods were Applewood and Cherrywood. Applewood, especially at 4 hours, had significantly higher intensities for most attributes. Most notably, Applewood was highest in Bitter, Burnt, Acrid and Creosote/Tar which are all sharp, aggressive flavor notes. Cherrywood regularly had the lowest intensities and had a much milder overall flavor than the rest of the samples.

CONCLUSION

All of the PCAs support, and are supported by, the findings from the ANOVA. The smoky flavor profile of products smoked for shorter amounts of time are not as distinguishable from each other as products smoked for longer amounts of time. The longer the product is in the smoker, the more the wood is being combusted and more volatiles are being released from the wood and picked up by the meat. This gives the products a higher overall flavor intensity the

longer they are in the smoker, but depending on the type of wood, different attributes of that smoke flavor are more prevalent.

Overall, the products smoked with Applewood have a higher overall smoky intensity and the products smoked with Cherrywood have a lower overall smoky intensity. At shorter smoking times, products smoked with Mesquite will have a Creosote/Tar characterization. At the longer smoking times, Applewood products have higher intensities for Ashy, Burnt, Pungent, Petroleum-Like, Creosote/Tar and Cedar.

This study was only done with pork, so results could differ with different types of products. The study has shown that the smoke flavor that imparts itself on products from different woods does have slight differences, especially the longer the product is smoked for and the differences in flavor may not be the same at different smoking times. Further study on more types of woods, types of products and longer smoking times could give more in depth information on the differences between the flavors.

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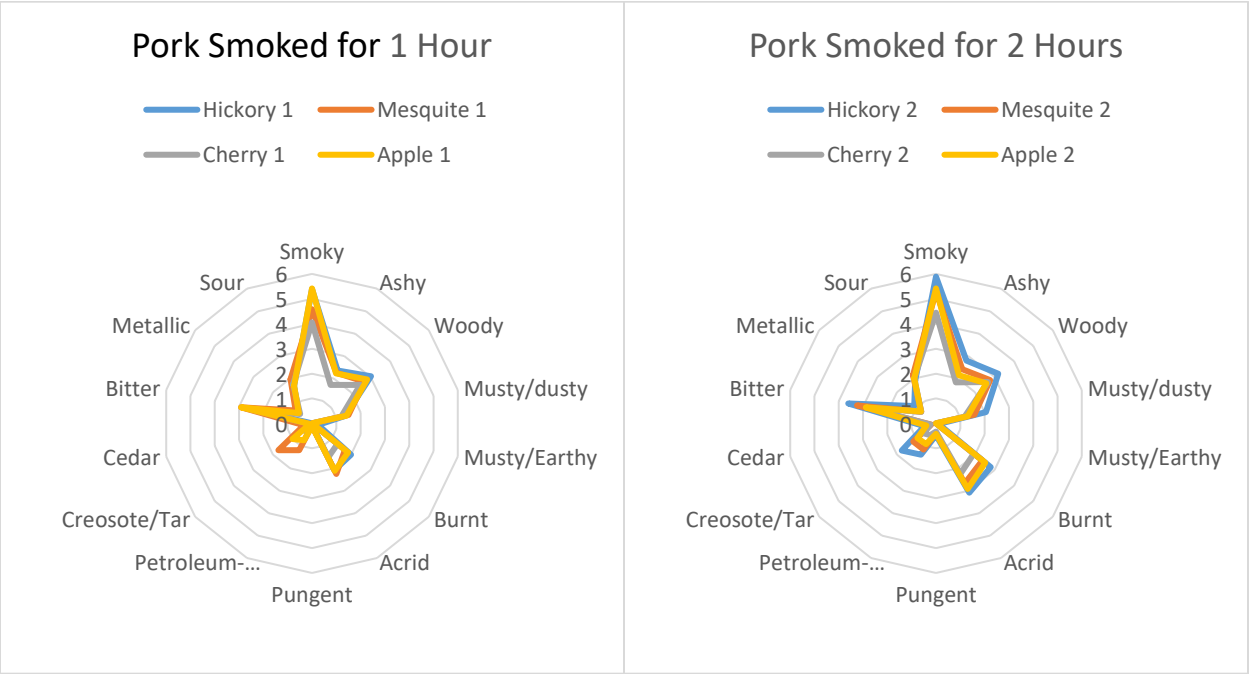
TABLES AND FIGURES

Figure 4. Spider plots of means of evaluation data separated by length of time



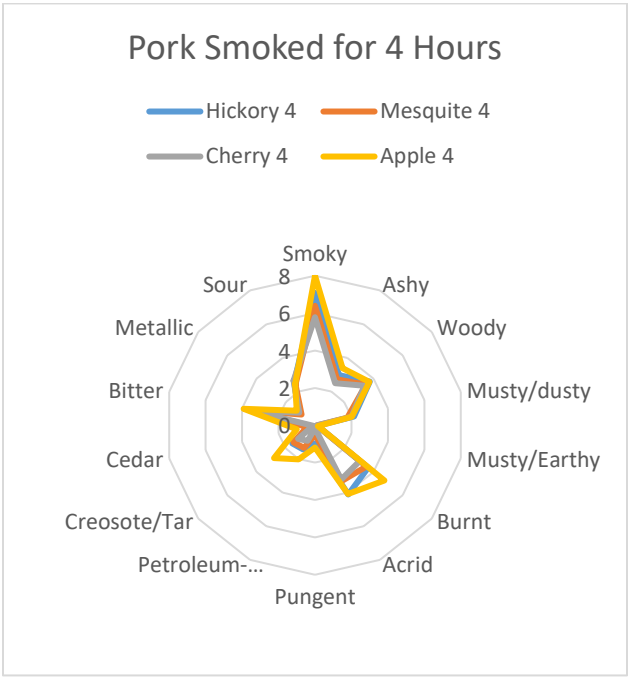


Figure 5. Spider plots of means of evaluation data separated by wood

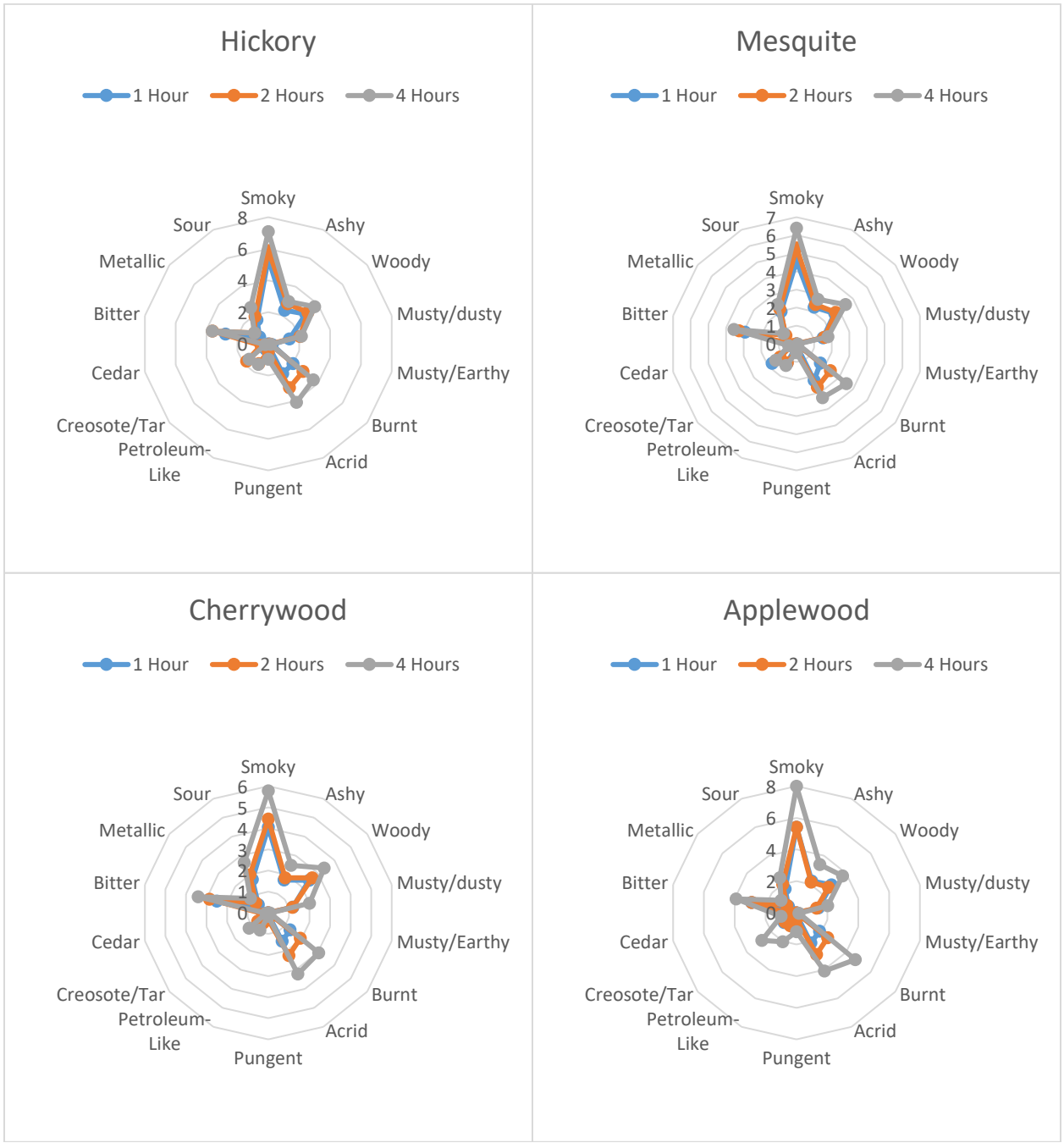
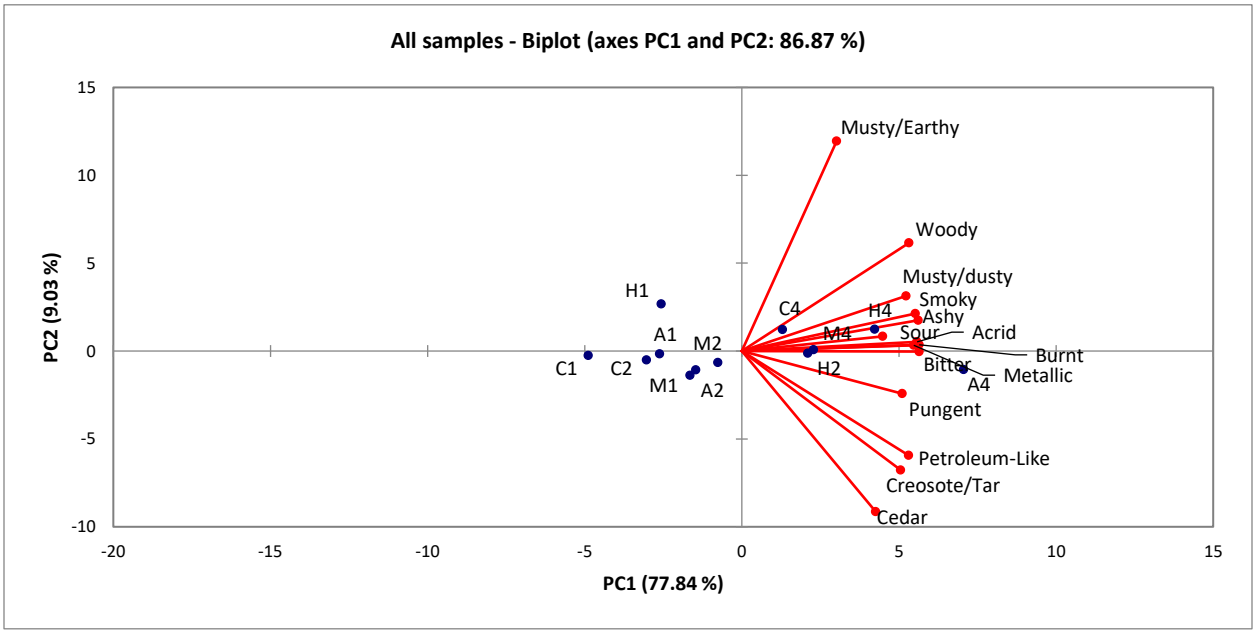
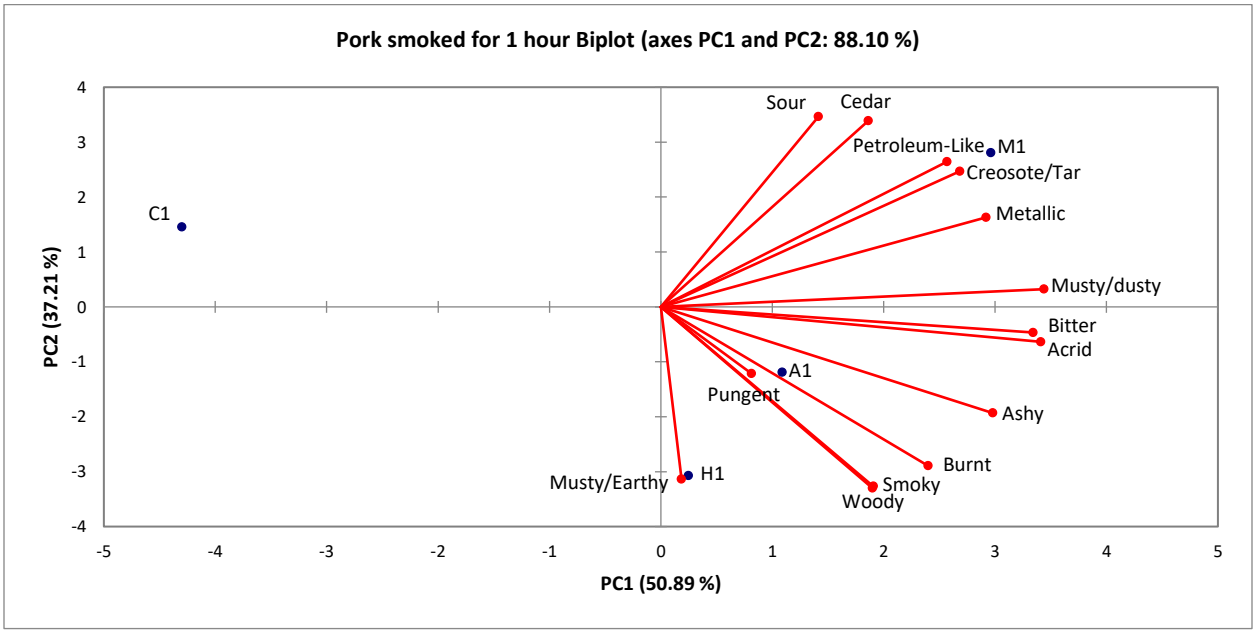


Figure 6. PCA biplot of PC1 and PC2 of all products



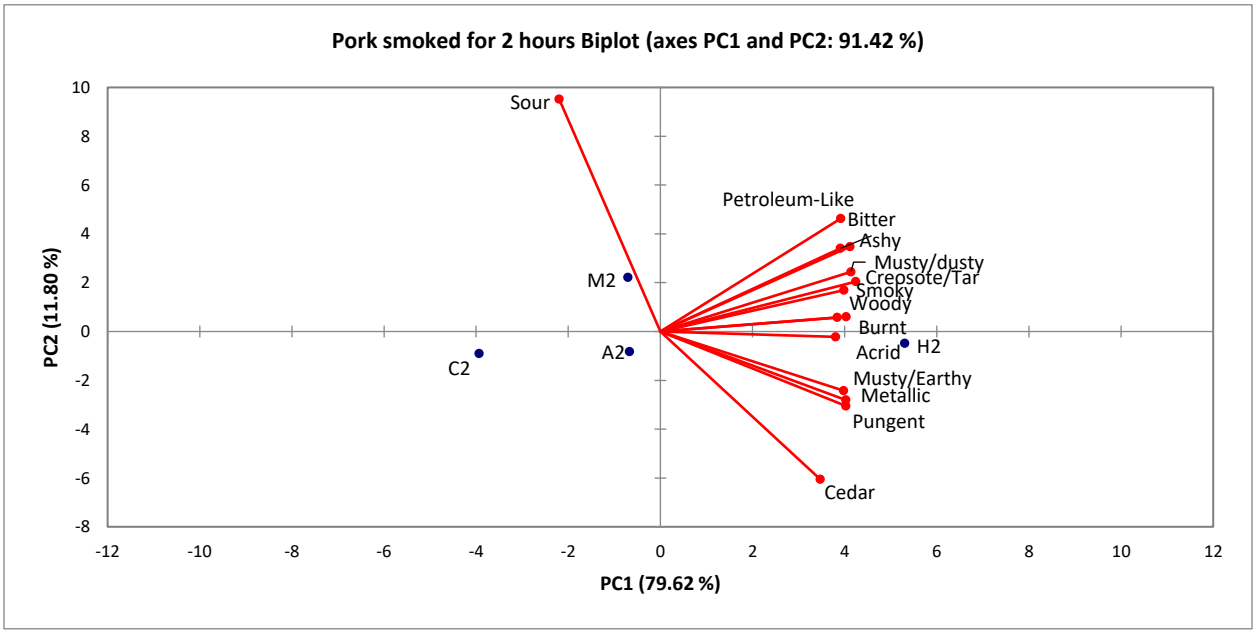
*Products are labeled with the first letter of the type of wood (H = Hickory, M = Mesquite, C = Cherrywood, A = Applewood) and hours it was smoked for (1, 2 or 4)

Figure 7. PCA biplot of PC1 and PC2 of products smoked for 1 hour



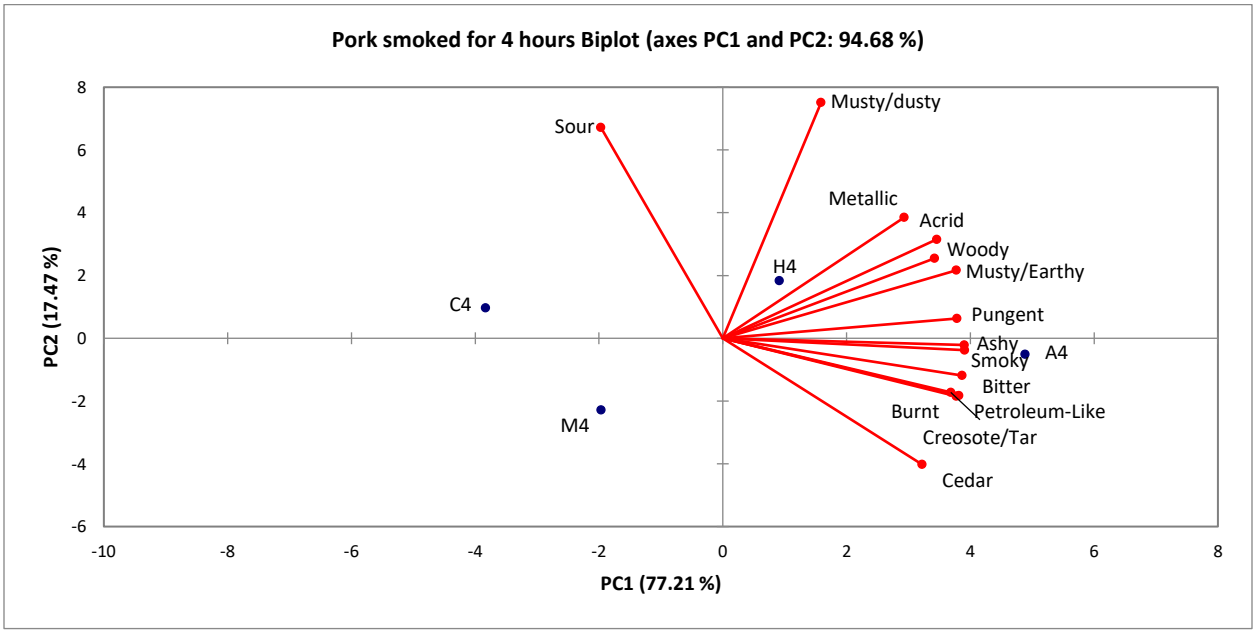
*Products are labeled with the first letter of the type of wood (H = Hickory, M = Mesquite, C = Cherrywood, A = Applewood) and hours it was smoked for (1)

Figure 8. PCA biplot of PC1 and PC2 of products smoked for 2 hours



*Products are labeled with the first letter of the type of wood (H = Hickory, M = Mesquite, C = Cherrywood, A = Applewood) and hours it was smoked for (2)

Figure 9. PCA biplot of PC1 and PC2 of products smoked for 4 hours



*Products are labeled with the first letter of the type of wood (H = Hickory, M = Mesquite, C = Cherrywood, A = Applewood) and hours it was smoked for (4)

Chapter 5 - Effect of smoking time on smoke flavor profile

ABSTRACT

Smoking is a method of cooking food that was originally used as a preservation method. With today's technology, such as refrigeration, smoking is used to impart specific flavors deemed desirable by the consumer. Smoking is a slow process and many popular restaurants that smoke their own products find that their claims of smoking for long periods of time are beneficial to their image. This study used a highly trained and skilled descriptive sensory panel to evaluate pork samples that were smoked for different lengths of time to test how the flavor profile changed over time. By looking at the spider plot comparing the products from the shortest and longest smoking times, and by confirmation of a MANOVA, the smoke flavor profile has large changes over time. For most attributes, the intensities increased with the amount of time the product was in the smoker. The only exceptions were Musty/Earthy and Sour. The principal component analysis showed that 53.88% of the variance in the data set can be explained by one PC, which is driven by Smoky, Ashy, Woody, Burnt, Acrid, Creosote/Tar and Bitter. The regression analysis confirmed that Smoky, Ashy, Acrid, Creosote/Tar and Bitter are all at least moderately correlated with the time the product spent in the smoker.

INTRODUCTION

Smoking is a cooking technique where wood is heated to produce smoke and the heat of that smoke cooks the food. Many products are smoked such as meats, fish, poultry and cheeses. There are many advantages to smoking products such as killing bacteria, preventing fats from becoming rancid, extending the shelf life and creating distinguishable flavors and colors (Marianski et al. 2007).

A lot of research has been done on what compounds lead to the flavor and aroma of smoke (Guillén et al. 2006, Jerkovic et al. 2007, Xie et al. 2008, Yu et al. 2008, Majcher et al. 2011). Many studies have led to the conclusion that phenolic compounds are the most important to the sensory characteristics of smoked foods (Kostyra and Baryłko-Pikielna 2006, Cardinal et al. 2006, Varlet et al. 2006, Jerković et al.2007, Jónsdóttir et al. 2008).

There are also studies that have linked the compounds responsible for smoke flavor and aroma to sensory attributes. Chambers et al. (1998) associated some of these compounds with attributes such as ashy, brown spice, burnt, burnt sugar, close, creosote, cured maple, Sulphur and woody. Ojeda et al. (2002) did a similar studies and found chemicals that match the attributes burnt, fruity, combustible, sharp, floral, caramellic, sweet, pungent, acidic, wood, medicinal, spice and musty.

While listing which compounds are important is helpful, the amount of these compounds in the smoked product is what leads to specific aroma and flavor profiles. Every compound has a different taste and aroma threshold, and those thresholds are even different depending on the carrier (Wasserman 1966).

The longer the products are in the smoker, the more compounds from the smoke the product will absorb. The objective of this study was to see how the length of time a product is smoked for effects the smoke flavor profile of that product. This experiment is only looking at the flavor profile of the smoke flavor, no flavors that are related to the raw product. It is expected that most, if not all, of the attributes will rise in intensity as the amount of time the product spends in the smoker goes up.

MATERIALS AND METHODS

Samples

The focus of this study was on the smoke flavor, but in order to lower variance due to the raw samples, pork loins were used as the starting material for every sample. The pork loins were a national brand and bought at the local super market. The full pork loins were cut into 2 pieces of the same size and loose pieces of fat were cut off and not used.

Samples were smoked for different lengths of time: 2.5, 5, 7.5, 10, 12.5 and 15 hours. There was also a 0 time point. The samples that were for the 0 time point were roasted in the oven until they reached an internal temperature of 145 °F. There were three samples for each time point, of which there was 7, so 21 samples total.

Before the samples were served, they were heated in a 350° F until they reached an internal temperature of 145 °F. The heated samples were cut into ½" squares. Each piece had one side that had direct contact with the smoke. While areas of the original pork loin that were mostly fat were cut off, due to the nature of the product, each piece may not have had the same ratio of fat to protein. This was controlled to the best of the researcher's ability with the equipment available.

The samples were served in capped 3.25 oz plastic containers (Solo, P325N, Dart, Mason, Michigan, USA) on top of heated bricks. Each panelist received 4 pieces of the same sample.

Wood Samples

Hickory wood was used in this study (Cowboy Brand, Cowboy Charcoal, LLC, Albany, KY, USA). The wood was in the form of small wood chips, ranging from about a ½ cm to 3 cm. The wood was sold with the intent that they are used in an electric smoker.

Smoking

The samples were smoked in an electric smoker (30 lb Digital Country Style Smoker, Model 40903, The Sausage Maker Inc, Buffalo, NY, USA) set at 200 °F. Four cups of wood chips, which were soaked in two cups of deionized water, were put in a shallow pan and placed on the electric burner at the bottom of the smoker. New wood chips were put into the smoker every 2.5 hours in order for there to always be smoke produced. A metal hood was about 3 inches above the pan so that the smoke was more evenly distributed in the smoker.

All samples were put into the smoker together. Three samples were taken out at each time point. The samples that were taken out together came from different areas of the smoker (different distances from the heat/smoke source).

Panelists and Sensory Procedure

Six highly trained panelists (1 male and 5 females, ranging in age from 50-70) participated in this study. All panelists were trained at the Kansas State University Sensory Analysis Center for a minimum of 120 hours and had experience evaluating the flavors of many food and beverage products.

Five evaluation sessions took place. 4 samples were evaluated at 4 of the 1.5-hour sessions and 1 session had 5 samples. This allowed for a minimum of 15 minutes of evaluation per sample and a 5-minute cleansing period between samples.

The samples were presented one at a time in 3.25 oz cups with lids, and labeled with a random 4-digit code. The researcher knew which code referred to which sample, but the panelists were blind to this information. The only information offered to the panelists were that the samples were smoked pork.

In order to evaluate the samples, the consensus method was used. The panelists individually evaluated the samples by rating the intensity of each flavor attribute on the ballot from 0 to 15 at 0.5 increments. After they individually evaluated the samples, the panel leader (who is one of the six panelists) led discussion and the panel came to a consensus for the intensity of each attribute and submitted one flavor profile per sample.

The ballot included the terms Smoky, Ashy, Woody, Musty/Dusty, Musty/Earthy, Burnt, Acrid, Pungent, Petroleum-Like, Creosote/Tar, Cedar, Bitter, Metallic and Sour. There were references for each term and a list of these can be seen in Table 1.

During the cleansing period, the panelists had access to unsalted crackers, whole milk (a minimum of 3.25% fat) and deionized water to help neutralize the flavors of the previous sample before moving to the next sample.

Data Analysis

The data was analyzed using SAS (Version 9.2, SAS Institute, Inc., Cary, NC) and XLStat (Version 2015.3.01, Addinsoft, New York, New York, USA). The first test ran, using SAS, was a multivariate analysis of variance (MANOVA) to make sure that there is a difference between the samples. Wilks' Lambda test statistic was used to test the null hypothesis (The length of time the product is smoked for leads to no sensory differences).

XLStat (Version 2015.3.01, Addinsoft, New York, New York, USA) was then used to run a principal component analysis (PCA), which consolidates the data and explains it in as few variables as possible, called principal components (PC). A biplot from the PCA will show any trends in the data with the attributes that explain that data. The eigenvectors for each PC will show which attributes are the drivers, in other words are most important, in that PC.

The last analysis run will be a linear regression analysis. Because the objective is to see how the smoke profile changes over time, a regression analysis will show how strong the correlation is between the time the product was in the smoker and the intensity of attributes.

RESULTS AND DISCUSSION

Overall the intensities of the products increased over time (Figure 10). Cedar and Petroleum-Like were not found in any of the samples, so they were eliminated for the data analysis. All attributes except Musty/Earthy went up in intensity over time. Also, Metallic first went down but then went higher than the T0 intensity. The attributes burnt, acrid, musty/dusty and pungent did not appear until at least the third time point (T-5).

Figure 11 shows a spider plot of T-0, the shortest smoking time (T-2.5) and the longest smoking time (T-15). Musty/Earthy, Bitter, Metallic and Sour were all given intensities for the T-0 samples. Because only the smoke flavor was being evaluated by the panelists, all attributes should have gotten zeros for the T-0 samples. It is very difficult for the trained panelists to pull out what attributes are derived strictly from the smoking process and what comes from the raw product.

The differences from T-2.5 to T-15 is quite drastic and can easily be seen in Figure 11. Almost all attributes had higher intensities in T-15 except Musty/Earthy and Sour. According to the multivariate analysis of variance, at least one time point was significantly different than the others. The Wilk's Lambda test, used in conjugation with the MANOVA, resulted in a p-value of 0.0105. So we can say that at a 95% confidence level, at least one time point is significantly different.

Using only the first two PCs from the PCA, 69.39% of the variance was explained. In fact, 58.88% of the variance was explained by only the first PC. The first PC was driven almost equally by many of the attributes: Smoky, Ashy, Woody, Burnt, Acrid, Creosote/Tar and Bitter. All attributes, except Musty/Earthy, were in the positive direction and Musty/Earthy only had a value of -0.048. Because the samples that were smoked longer are on the positive side of the biplot, this shows that the attributes that change the most, and have the largest impact on the smoke flavor profile over time, are those attributes driving the first PC.

The second PC is strongly driven by Musty/Earthy in the positive direction and Musty/Dusty in the negative direction. All other attributes have very little effect on the second PC. PC2 only explains 10.51% of the variance in the data, so even though it is the second most important principal component, it does not explain nearly as much as the first. The third PC explains almost as much variance as the second at 9.83%. This PC is strongly driven by Metallic only. The only attribute that doesn't strongly influence a PC is Pungent, which only had intensities at T-10 and 15. The eigenvectors of the first three PCs can be found in Table 6.

The upward trend of most attributes over time is shown quite clearly on the biplot of the first two PCs (Figure 12). The first few time point (T-0, 2.5 and 5) are all clustered on the left side of the graph and as you move right, the time points become higher. Most of the replicates are very close to each other on the biplot, showing consistency in the panel's performance and confirming the intensity rankings for that time point.

The last piece of analysis done was a regression analysis using the average scores for each time point. Table 7 shows the coefficient of determination (r^2) for the models *attribute* = time. The strongest correlations were for Bitter, Creosote/Tar, Smoky, Acrid and Ashy; which are mostly the same attributes that drove PC1. This analysis shows that the intensity of these

attributes are moderately-to-strongly positively correlated with the amount of time the product was in the smoker.

There were also attributes that had none or close to no correlation with the length of time. Musty/Earthy and Sour had extremely low r^2 values and Metallic, Pungent and Musty/Dusty had low values. These attributes are affected very little, or not, effected by the length of time a product is smoked.

CONCLUSION

The results of this experiment were as expected. Most of the attributes rose in intensity as the time the product spent in the smoker went up. Smoky, Ashy, Acrid, Creosote/Tar and Bitter were the attributes most correlated with time while Musty/Earthy, Sour, Metallic and Pungent were the least.

The principal component analysis combined many of the attributes (Smoky, Ashy, Woody, Acrid, Creosote/Tar and Bitter), almost equally, into one dimension which explained majority (58.88%) of the data. When looking at the first three PCs, 79.23% of the variance in the data is explained and all variables except Pungent are major drivers for 1 PC.

This experiment only looked at the effect of the smoke flavor in pork. While the panelists were only evaluating the attributes that are derived from the smoking process, that is difficult for them to do and more conclusive results can be driven if the same method was applied to other products that are smoked.

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TABLES AND FIGURES

Figure 10. Bar Graph of Average Intensities of Each Attribute at Each Time Point

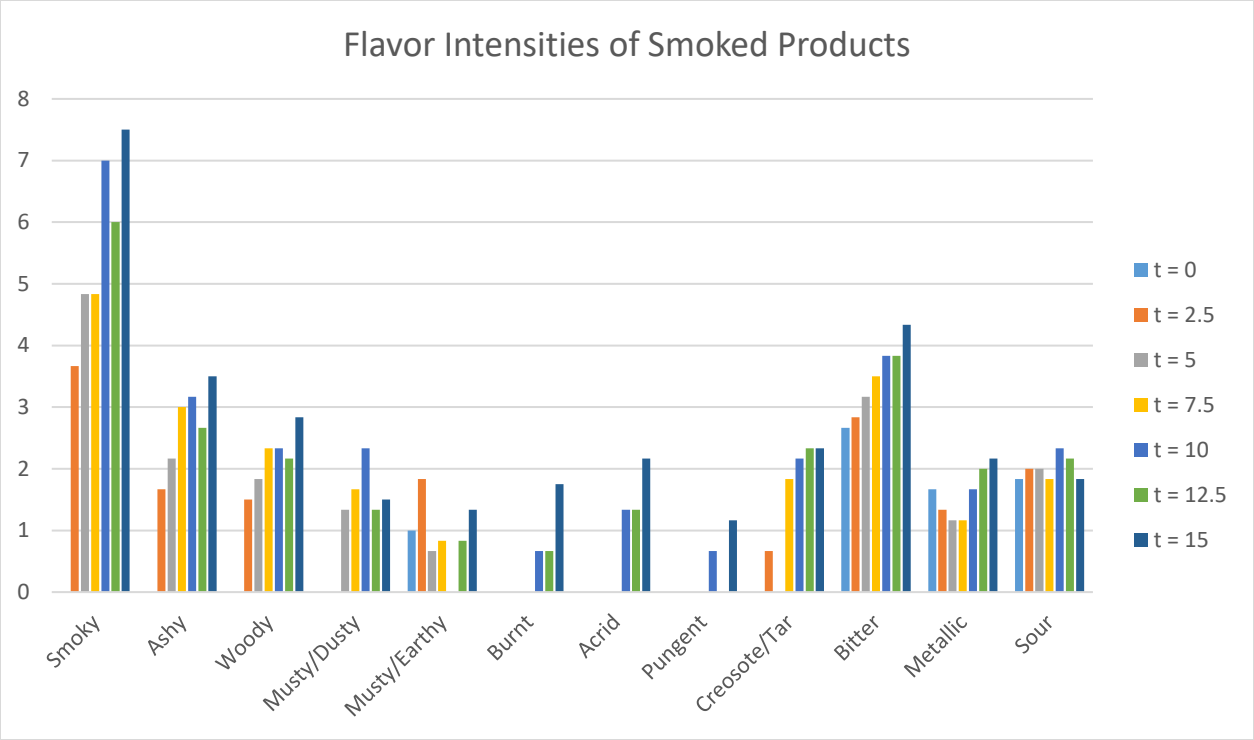


Figure 11. Spider Plot of Attribute Intensities from T-0, Shortest Smoking Time and Longest Smoking Time

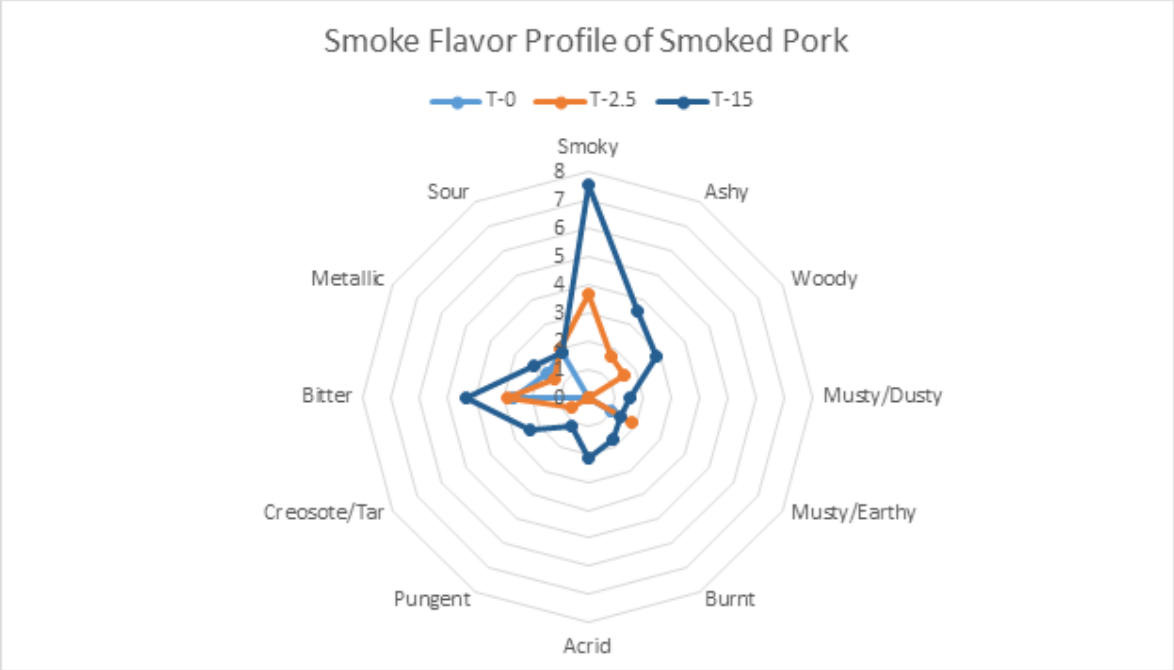
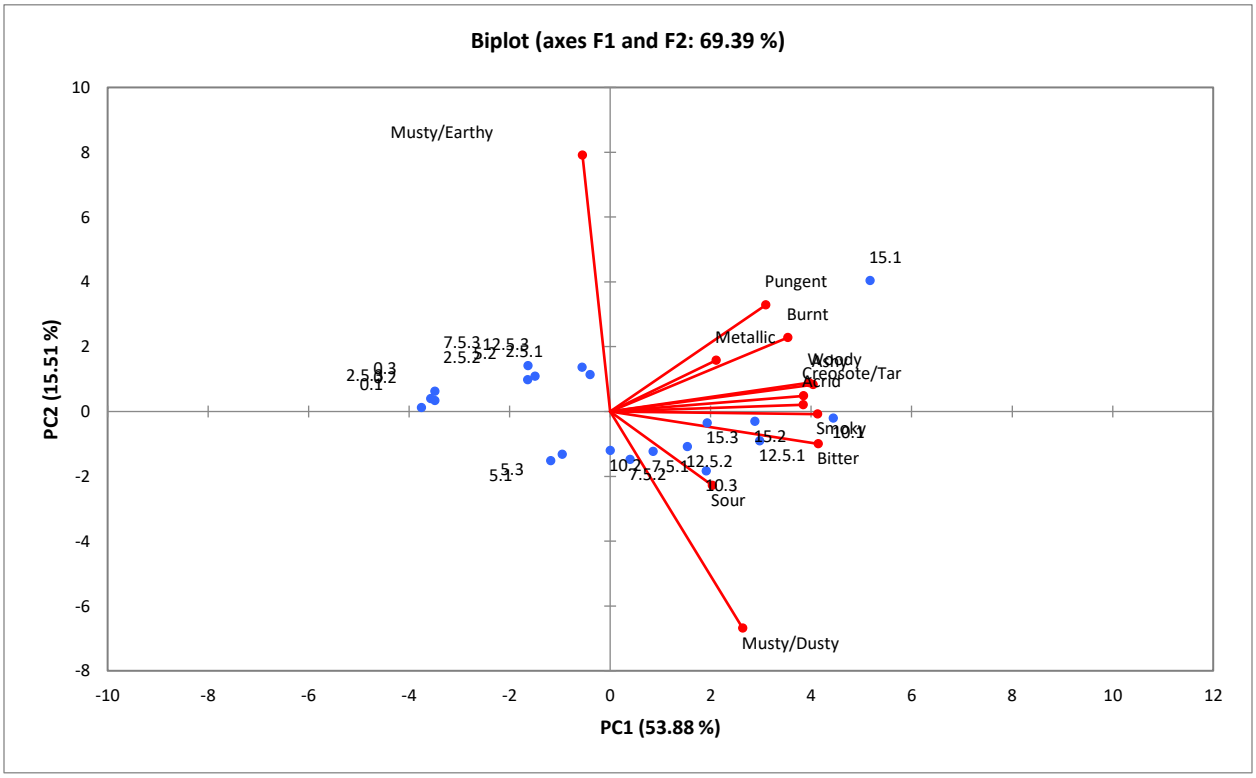


Figure 12. Biplot of PC1 and PC2 of entire data set



*Samples are labeled by hours smoked.batch number

Table 6. Eigenvectors for PC1, PC2 and PC3

	F1	F2	F3
Smoky	0.357	-0.007	-0.309
Ashy	0.349	0.071	-0.368
Woody	0.342	0.077	-0.348
Musty/Dusty	0.228	-0.578	-0.019
Musty/Earthy	-0.048	0.684	-0.201
Burnt	0.306	0.198	0.304
Acrid	0.333	0.018	0.293
Pungent	0.268	0.284	0.193
Creosote/Tar	0.333	0.041	-0.097
Bitter	0.358	-0.086	0.042
Metallic	0.183	0.137	0.610
Sour	0.176	-0.198	0.096

*The highlighted numbers refer to the major drivers of each PC

Table 7. Correlation Coefficients of the model *attribute* = time

Attribute	Coefficient of Determination (r^2)
Smoky	0.66
Ashy	0.52
Woody	0.49
Musty/Dusty	0.27
Musty/Earthy	0.01
Burnt	0.36
Acrid	0.58
Pungent	0.21
Creosote/Tar	0.67
Bitter	0.79
Metallic	0.14
Sour	0.03

Appendix A – List of Samples used for Lexicon Development

Bumble Bee Smoked Trout	Hy-Vee Fully cooked turkey bacon smoked cured
Bumble Bee Smoked Salmon	Kroger Turkey Bacon Smoked
Chicken of the Sea Smoked Salmon	Oscar Mayer Turkey bacon smoked cured
HyVee Smoke Alaska Sockeye Salmon	Farmland Naturally hickory smoked double smoked bacon
Private Selection Cracked Pepper Coho Salmon Alder Wood Smoked	Great Value Applewood Smoked Bacon
Allegro Hickory Smoke Marinade	Sterling Silver Applewood Smoked Bacon
Cookies Sweet Hickory Bar B Q Sauce	Jennie-Os Original Turkey Burgers Smoked Flavor Added
Figaro Hickory Liquid and Barbeque Marinade	Hillshire Farm Mesquite Smoked Turkey Breast
KC Masterpiece Barbecue Sauce Hickory Brown Sugar	Oscar Mayer Delifresh Smoked Turkey Breast
Weber Smoky and Think Hickory BBQ Sauce	Kroger Deli Style Lean Honey Smoked Turkey Breast
Belgioioso Smoked Fresh Mozzarella	Hillshire Farm Smoked Chicken Breast
Great Value Deli Style Sliced Provolone Cheese with Added Smoke Flavoring	Buddig Original Chicken Smoked
Murray's Smoked Gouda	BARS Smoked Deli Style Ham
Murray's Smoked Cheddar	Kroger Deli Style Lean Smoked Ham
Kroger smoke Flavor String Cheese	Hillshire Farms Smoked Ham
Figaro Mesquite Liquid Smoke and Marinade	Oscar Mayer Delifresh Smoked Ham
Curley's Mesquite Barbeque Sauce	Hormel Smoked Deli Ham
Lawry's Mesquite with Lime Juice	Hickory Pork Loin (2.5 hours)
Jack Daniel's Marinade Smoky Mesquite Liquid Marinade	Hickory Pork Loin (3 hours)
Colgin Liquid Smoke	Hickory Pork Loin (3.5 hours)
Budweiser Sweet and Smoke Barbeque Sauce	Hickory Pork Loin (4 hours)
Cookies Original Sweet and Smoky	Hickory Chicken Breast (2.5 hours)
Grill Mates Steak House Burdens Smoky Applewood	Hickory Chicken Breast (3 hours)
Sweet Baby Ray's Hickory and Brown Sugar Barbecue Sauce	Hickory Chicken Breast (3.5 hours)

Tone's Liquid Smoke	Hickory Chicken Breast (4 hours)
Hormel Bacon Lovers Naturally Wood Smoked	Hickory Potatoes (2.5 hours)
Hormel Naturally hardwood smoked applewood thick cut bacon	Hickory Potatoes (3 hours)
Hormel Naturally hardwood smoked brown sugar thick cut bacon	Hickory Potatoes (3.5 hours)
Hormel Naturally hardwood smoked pecanwood thick cut bacon	Hickory Potatoes (4 hours)
Farmland Naturally hickory smoked classic cut bacon slow smoked using real hardwood	Cherrywood Pork Loin (2.5 hours)
Kroger Fully Cooked Turkey Smoked Sausage	Cherrywood Pork Loin (3 hours)
Buddig Ham	Cherrywood Pork Loin (3.5 hours)
Smoked Cheddar	Cherrywood Pork Loin (4 hours)
Jack Daniel's Honey Smokehouse Barbeque Sauce	Cherrywood Chicken Breast (2.5 hours)
Allegro Hickory Smoke Marinade	Cherrywood Chicken Breast (3 hours)
Kroger Fully Cooked Smoked Sausage	Cherrywood Chicken Breast (3.5 hours)
Kroger Fully Cooked Beef Smoked Sausage	Cherrywood Chicken Breast (4 hours)
Oscar Mayer Selects Hardwood Smoked uncured Beef Sausage	Cherrywood Potatoes (2.5 hours)
Johnsonville Smoked Brats	Cherrywood Potatoes (3 hours)
Butterball Turkey bacon smoked cured original	Cherrywood Potatoes (3.5 hours)
Great Value Turkey bacon smoked	Cherrywood Potatoes (4 hours)

Appendix B - Ballot for Descriptive Sensory Analysis in Chapters 2, 3, 4 and 5

Panelist: _____ Sample code: _____ Date: _____

FLAVOR

Smoky	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Ashy	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Woody	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Musty/Dusty	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Musty/Earthy	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Burnt	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Acrid	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Pungent	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Petroleum-Like	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Creosote/Tar	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Cedar	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Bitter	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Metallic	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
Sour	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15

Appendix C – ANOVA table for differences between types of wood and hours smoked

Wood	Hour	Smoky	Ashy	Woody	Musty/ Earthy	Burnt	Acrid	Pungent	Petroleum-Like	Creosote/ Tar	Cedar	Bitter	Sour
Hickory	1	5.39 ^{d}	2.36 ^{cd}	3.03 ^{abcd}	0.25 ^{a}	2.0 ^{efgh}	2.08 ^{cd}	0.08 ^{c}	0.39 ^{e}	0.36 ^{e}	0.00 ^{c}	2.78 ^{cd}	1.67 ^{d}
Mesquite	1	4.58 ^{e}	2.25 ^{d}	2.69 ^{cd}	0.00 ^{b}	1.69 ^{gh}	2.25 ^{bcd}	0.08 ^{c}	1.19 ^{bcd}	1.72 ^{bc}	0.33 ^{bc}	2.92 ^{bcd}	1.97 ^{cd}
Cherry	1	4.06 ^{e}	1.72 ^{f}	2.47 ^{d}	0.00 ^{b}	1.31 ^{h}	1.50 ^{d}	0.08 ^{c}	0.44 ^{e}	0.39 ^{de}	0.08 ^{bc}	2.50 ^{d}	1.75 ^{d}
Apple	1	5.42 ^{d}	2.22 ^{de}	2.83 ^{bcd}	0.00 ^{b}	1.86 ^{fgh}	2.11 ^{cd}	0.11 ^{c}	0.75 ^{cde}	1.00 ^{bcde}	0.08 ^{bc}	2.92 ^{bcd}	1.67 ^{d}
Hickory	2	5.89 ^{cd}	2.81 ^{bc}	3.19 ^{abcd}	0.11 ^{ab}	2.81 ^{cde}	3.08 ^{abc}	0.47 ^{bc}	1.39 ^{abc}	1.75 ^{b}	0.47 ^{b}	3.61 ^{a}	1.92 ^{d}
Mesquite	2	5.31 ^{d}	2.42 ^{cd}	2.78 ^{bcd}	0.00 ^{b}	2.39 ^{defg}	2.67 ^{bc}	0.36 ^{c}	1.17 ^{bcd}	1.17 ^{bcd}	0.19 ^{bc}	3.25 ^{abc}	2.14 ^{bcd}
Cherry	2	4.44 ^{e}	1.83 ^{ef}	2.67 ^{cd}	0.00 ^{b}	1.94 ^{fgh}	2.25 ^{bcd}	0.33 ^{c}	0.53 ^{de}	0.64 ^{de}	0.22 ^{bc}	2.86 ^{cd}	2.00 ^{cd}
Apple	2	5.42 ^{d}	2.14 ^{def}	2.58 ^{d}	0.00 ^{b}	2.53 ^{def}	2.92 ^{bc}	0.42 ^{c}	0.92 ^{bcde}	0.94 ^{cde}	0.39 ^{bc}	2.89 ^{bcd}	2.00 ^{cd}
Hickory	4	7.08 ^{b}	2.97 ^{ab}	3.75 ^{a}	0.14 ^{ab}	3.64 ^{b}	4.11 ^{a}	0.97 ^{ab}	1.44 ^{ab}	1.56 ^{bc}	0.19 ^{bc}	3.64 ^{a}	2.56 ^{ab}
Mesquite	4	6.39 ^{bc}	2.72 ^{bc}	3.47 ^{ab}	0.08 ^{ab}	3.53 ^{bc}	3.31 ^{ab}	0.50 ^{b}	1.33 ^{bc}	1.47 ^{bc}	0.44 ^{b}	3.56 ^{ab}	2.42 ^{abc}
Cherry	4	5.78 ^{cd}	2.5 ^{cd}	3.39 ^{abc}	0.08 ^{ab}	3.06 ^{bcd}	3.22 ^{ab}	0.17 ^{c}	0.92 ^{bcde}	1.17 ^{bcd}	0.11 ^{bc}	3.41 ^{abc}	2.64 ^{a}
Apple	4	8.00 ^{a}	3.39 ^{a}	3.72 ^{a}	0.17 ^{ab}	4.75 ^{a}	4.08 ^{a}	1.19 ^{a}	2.03 ^{a}	2.81 ^{a}	1.00 ^{a}	3.92 ^{a}	2.44 ^{abc}

Appendix D – SAS Code for Chapter 5 MANOVA

```
proc glm data=length;
class time;
model Smoky Ashy Woody MustyDusty MustyEarthy Burnt Acrid Pungent CreosoteTar
Bitter Metallic Sour = time;
manova h=time /printe printh;
run;
```