BREW METHODS EFFECT ON COFFEE FLAVOR AND AROMA

A Thesis

by

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ABSTRACT

Coffee is one of the most popular aromatic hot drinks in the world. Numerous coffee brewing methods have been developed to make a cup of coffee. In industry, coffee flavor and aroma is determined by using a method called cupping, but in order to quantitate flavor and aroma in coffee, descriptive sensory is a better option. This study identified how brew methods influence coffee aroma and flavor. Four different roast level Folgers® commercial coffee (Breakfast blend, Classic roast, 100% Colombia and Black silk) were brewed by four brewing methods (pour over, drip, French press, and cold brew) and were tested using a trained descriptive panel using the World Coffee Research (WCR) coffee lexicon. Twenty-five main aroma attributes and thirty-five main flavor and texture attributes of coffee were used. Cold brew method produced the mildest coffee among the four brew methods while drip produced a much stronger coffee. The sensory aroma and flavor differences between different coffee types were not as great as differences between brew methods. From chemical tests, Brix percentage and TDS (Total Dissolved Solids) differed across coffee types and brew methods. Chemical attributes were closely associated with overall impact, body fullness, bitter basic taste and roasted and burnt flavor aromatics. Volatile compounds ($n = 271$) were identified. Forty-four volatile aromatic compounds differed across coffee types while thirty-seven volatile aromatic compounds differed across brew methods. Folgers® 100% Colombia coffee showed a difference from the other three coffee types by showing higher ($P < 0.05$) amount of volatile compounds, especially in 2-butenal, and 1-(2-

hydroxyphenyl)-ethanone (beany aroma). Cold brewed Folgers® 100% Colombia was high on sweet, overall sweet flavor as well as 2,3-hexanedione. The preparation method is a critical factor affecting coffee flavor and aroma. Coffee from the cold brew method was more fruity, floral and sweet whereas coffee from the drip or French press methods were roasted, burnt, and ashy.

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All the work for the thesis was completed by the student, in collaboration with Hannah Laird and Blythe Beavers of the Department of Animal Science.

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CHAPTER I

INTRODUCTION

Coffee flavor and aroma is determined by the industry using a method called cupping. Trained evaluators rate coffee for quality attributes based on a 100 point scale (Donfrancesco et al., 2014). Donfrancesco et al. (2014) showed that cupping, while an effective quality assessment tool, was not a method to quantitate flavor and aroma in coffee. Kansas State University, Texas A&M University and World Coffee Research (WCR) developed a sensory lexicon for coffee where 108 attributes for flavor and aroma were identified (WCR, 2016). The coffee lexicon provides a method for quantifying differences in aroma and flavor of coffee using standardized references and scales. Now that a tool for aroma and flavor of coffee has been determined, this tool can be used to understand factors that affect the aroma and flavor of coffee. Our objective was to evaluate four standard commercial coffees (Mild, Medium, Medium-dark, and Dark) using 35 main aroma and flavor attributes from the coffee lexicon. These commercial coffees were roasted and blended to be consistent in aroma and flavor attributes within the coffee types. Brew method affected the extraction of solids and aroma and flavor attributes in coffee (Rao, 2010; Caporaso, 2014). Therefore, four brewing methods were used (pour over, drip, French press, and cold brew) to understand how brew method affected the aroma and flavor of the four commercial coffees. Aroma and flavor were determined using an expert trained descriptive coffee panel. Additionally, the amount of extractable solids, pH, and volatile aromatic compounds were determined.

CHAPTER II

LITERATURE REVIEW

Introduction

Coffee was discovered as a beverage extracted from roasted coffee beans around the 15th century, it quickly spread around the world and became one of the most popular beverages of modern society. Coffee is the second most popular aromatic hot drink in the world behind tea. Consumption levels continue to increase all around the world because of its desirable flavor characteristics (Parliament, 1995).

According to the latest statistics published by the International Coffee Organization (ICO), 150.2 million 60 kg bags of coffee were consumed in 2014 (Figure 2.1). The average annual growth rate of global coffee consumption since 2011 is 2.3%. Coffee demand is strong in many countries, especially in traditional markets like the European Union, Canada, USA, and Japan, although, the biggest potential markets are the emerging markets like Russia, Australia, South Korea, and Turkey (ICO, 2016).

With one-sixth of the world's coffee consumption, the United States is the largest coffee consuming country in the world (ICO, 2016). The National Coffee Association (NCA) in 2016 reported that from 2011 to 2016 (Figure 2.2), American per capita consumed at least 1.5 cups of coffee per day. An online survey conducted by the National Coffee Association (NCA) in 2016 from January 11 to January 26, 2,782 respondents were asked how many cups of coffee they drink per day. The survey results revealed that the per capita coffee consumption of respondents in the age bracket between 30 and 39 years, and 70 and over consumed the most coffee which amounted to 1.85 and 1.95 cups per day. Males on average consumed 1.78 cups per day while female consumed 1.5 cups per day (Figure 2.3).

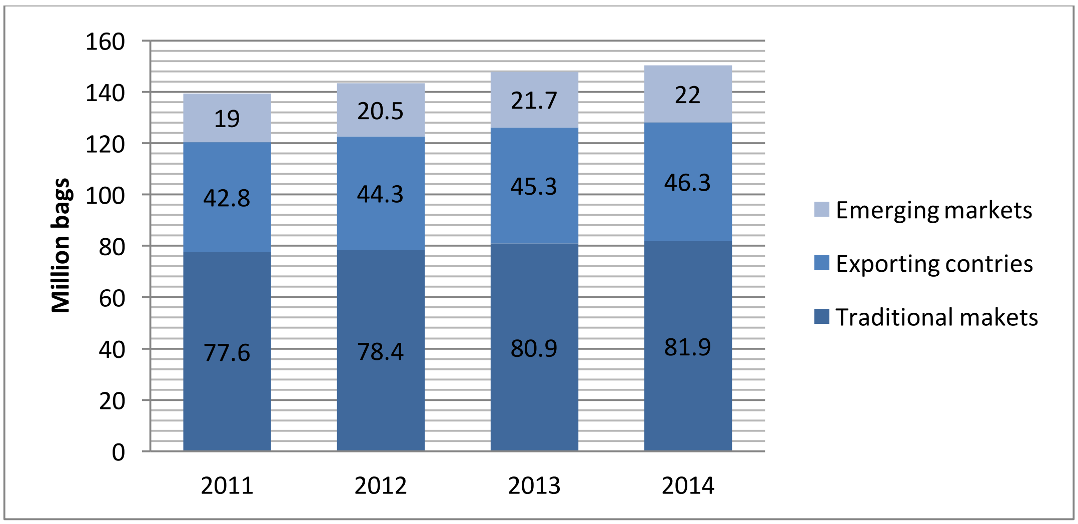

Figure 2.1 The global coffee consumption since 2011 (International Coffee Organization, 2016).

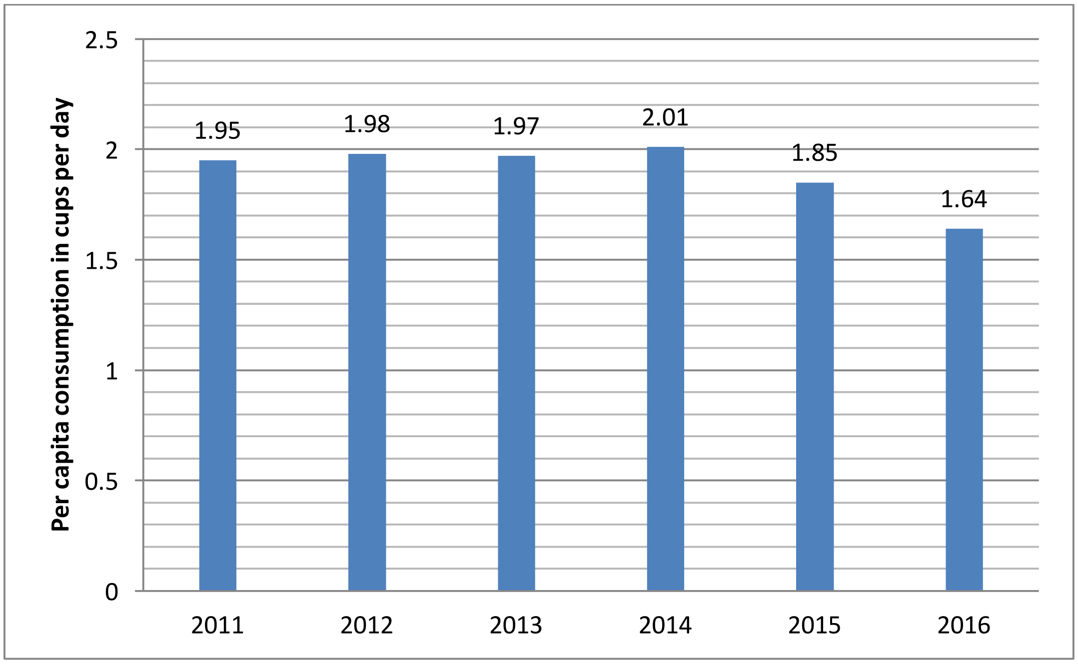

Figure 2.2 Total coffee per capita consumption in the United States from 2011 to 2016 in cups per day (National Coffee Association, 2016).

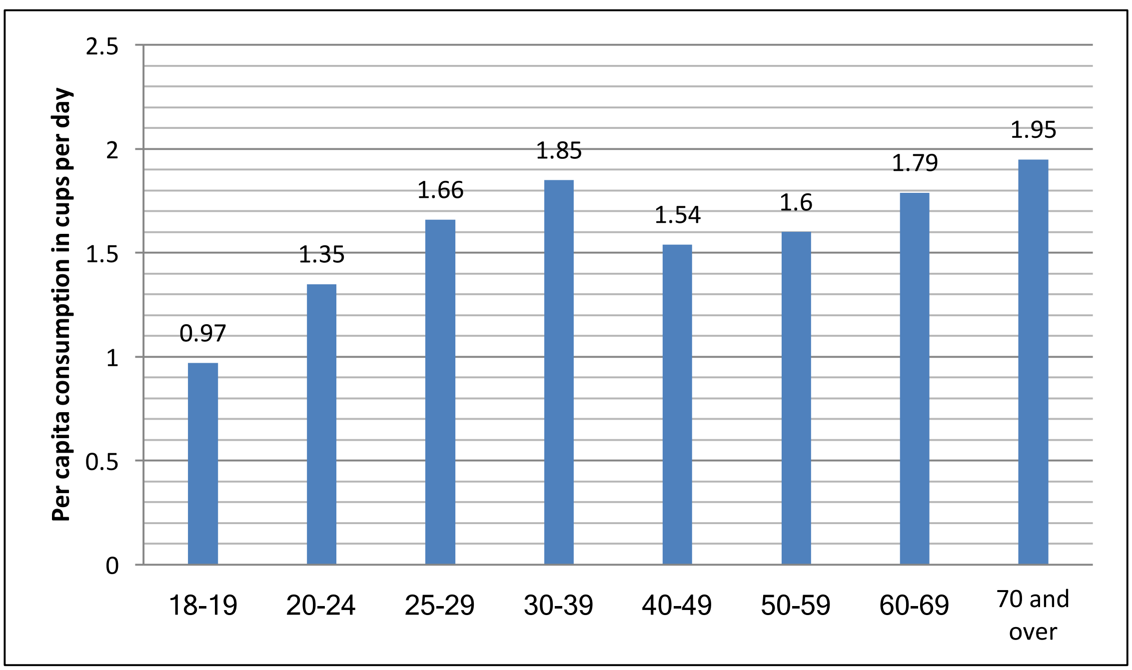

Figure 2.3 Total coffee per capita consumption in the United States, by age group in cups per day (National Coffee Association, 2016).

Coffee Processing

Coffee is part of the Rubiaceae family, genus, *Coffea*. *Coffea*, overall, the genus has more than 80 species. Only *Coffea arabica L*. and *Coffea canephora var. robusta* are the two major species responsible for coffee production, and these two species have real economic importance around the world. Approximately 60% to 70% of the world's coffee production is represented by *Coffea Arabica* while the *Coffea Robusta* variety represents a large percentage of 30% to 40% of global production. (International Trade Centre, 2011; Farah, 2012)

From plant to cup, coffee goes through a series of processing steps. During processing, there are many factors that can influence the final product. The steps during production of green beans including harvesting methods, processing methods, and roasting degree, all could influence the quality of the final coffee (Farah, 2012).

The first critical step in coffee production is harvesting the crop. Coffee fruits on average reach maturity around nine months, and then are picked either by hand or mechanically depending on the farm size (Winkler, 2014). During this period, the degree of maturation and the treatment given to fruit to avoid microorganism growth both affect the quality of the coffee fruit. Fungus contamination and growth during harvesting, drying, and storage of the seeds are critical points during the coffee production (Farah, 2009). After harvest, the beans need to be separated from the pulp which is called processing. There are two main processing methods, dry processing, and wet processing. In dry processing, the over-mature fruits will be spread out in the sun or placed in mechanical dryers in order to dry to a moisture content of 9% to 13% (Winkler, 2014). The process is both simple and cheap making it popular for *Robusta* and *Arabica* in Brazil and Africa where sun and space are abundant (Winkler, 2014). The wet processing is mainly used for *Arabica*. During wet processing, the beans are selected by flotation then pulped and fermented. These processes remove the coating called mucilage which adheres to the ripe fruit; then the beans are sent to get washed and dried. The quality of coffee using wet processing tends to be higher than using dry processing because of the fermentation period. During wet processing, beans are dried to at least 14% moisture, which is equivalent to a water activity of 0.75. From a microbiological point of view, a moisture content of less than 13% is preferred for later storage. Next, the dried beans are processed to remove the husk and the parchment and then sorted for different criteria before roasting (International Trade Centre, 2011; Winkler, 2014).

Roasting is a heat process that turns green coffee beans into fragrant, dark brown beans. This step brings out the aromas and flavors that are locked inside the green beans. During the roasting process, many chemical reactions occur. The main reactions include the Maillard reaction between amino acids and sugars, Strecker degradation, degradation of sugars, minor lipid degradation and interaction between intermediate decomposition products (Carprioli et al., 2015).

Coffee roasting degree is determined based on the color evaluation of roasted beans. Four main roasted degrees are defined as following: 1) light – light brown in color, no oil on the surface (e.g. Half-City Roast, Cinnamon Roast); 2) medium – medium brown in color (e.g. Classic Roast, Regular Roast, City Roast, American Roast);

3) medium-dark, rich, dark color with some oil on the surface (e.g. Colombia Roast, Full-City Roast, Vienna Roast, After-Dinner Roast); and 4) dark – shiny black color with oil surface (e.g. French Roast, Spanish Roast, Espresso Roast, Italian Roast; National Coffee Association of USA, 2015).

Coffee Brew Methods

Coffee has been around since the 15th century and is one of the most popular drinks in the world. Numerous coffee brewing methods have been developed depending on geographic, cultural, social context as well as a personal preference (Petracco et al., 2001; Illy et al., 2005). Figure 2.4 and Figure 2.5 show the results of an online survey conducted by the National Coffee Association (NCA) from January 11 to January 26, 2016. One thousand five hundred seventy-one U.S. survey respondents were asked which preparation method they have used for their past-day coffee consumption. Fifty percent of the respondents reported having consumed coffee brewed by a drip coffee maker the day before (Figure 2.4). However, the usage of drip coffee makers had dropped from 77% in 2010 to 50% in 2016 according to NCA (2016) which means people are using more and more different coffee preparation methods (Figure 2.5). Recently, pour over, French press, and cold brew are emerging coffee preparation methods.

Drip brewing has become one of the most popular brewing methods because it is fast and automatic. The drip brewing process drips hot water over coffee grounds, through a filter, and into a pot. Despite its popularity, the drip brewing process extracts undesirable acids from the grounds. Drip machines concentrate the flow of hot water on the central grinds while leaving the periphery grounds relatively unsaturated. Coffee is wasted because the extraction process is incomplete. To overcome this problem, some patented coffee makers feature a mechanical agitator to equally expose all the grinds to the brewing process. Drip machines are tall because the filter basket is located above the pot. The most significant drawback of drip machines is that they produce mediocre coffee with a high acid content (Husted, 2000).

The pour over brewing method is a manual filter brewing method which is simply pouring a predetermined quantity of hot water at a controlled rate over a bed of coffee grounds. The grounds are contained within a filter that the hot water seeps downward to engage the coffee grounds to extract soluble materials (Sellers, 1994). The pour over method can produce good quality coffee because the water temperature and filter time can be manually controlled (Kingston, 2015).

A French press is a type of coffee brewer in which coffee grounds are steeped directly in a pot with hot water before being filtered. Developed in Italy in the 1930s, the French press became popular in post-World War II France, and in recent years has grown in popularity in the United States (Kenneth, 2001). This press generally consists of a metal or glass pot and a lid through which a plunger with a mesh filter screen fits. Coffee is brewed in a French press by mixing the grounds and hot water directly in the pot with the lid on and the plunger in the uppermost position. After the coffee has reached proper extraction time, the plunger is pressed down slowly to move the filter toward the bottom of the pot. As the coffee grounds are in direct contact with the water, most of the extracted compounds are present in the coffee, making coffee from the French press stronger and sediment or finer particles that are not filtered are present in the coffee (Caprioli et al, 2015).

Cold brew is a low-temperature extraction method. The exact process varies by equipment maker, but cold brew generally involves mixing coffee grounds with cold or room-temperature water, allowing the mixture to sit for a minimum time of approximately 24 hours, and then filtering it into a carafe (Kingston, 2015). The flavor of cold brew has relatively high levels of certain positive flavor compounds including aldehydes, diketones, pyrazines and caramel compounds such as furaneol, as well as much lower levels of certain undesirable coffee flavor compounds including guaiacols and other phenolic compounds (Rizzi and Gutwein, 1994).

It is vitally important that coffee is brewed properly, especially to the specialty coffee community. Around the 1950s, Pan American Coffee Bureau in New York conducted studies that left brewing quality to science by introducing measurable results for extraction related to brewing strength. The Bureau combined two parameters of brew strength and the amount of solids extracted. Use of these three measures determined that the ideal extraction was between 18 and 22 percent and is a combination of particle size in the grind, brewing time and water temperature, regardless of coffee quality (Kramer, 2013). In the recent few decades, the use of electronic refractometers and other coffee technologies have made the measuring easier.

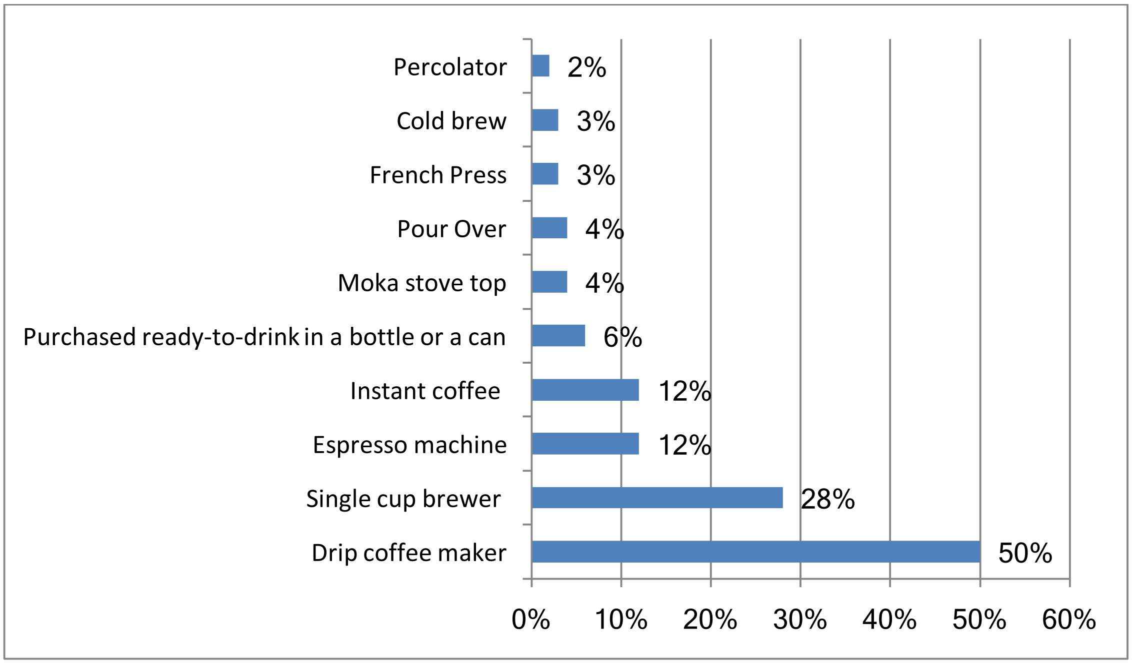

Figure 2.4 Method of preparation among past-day coffee drinker in the United States (National Coffee Association, 2016).

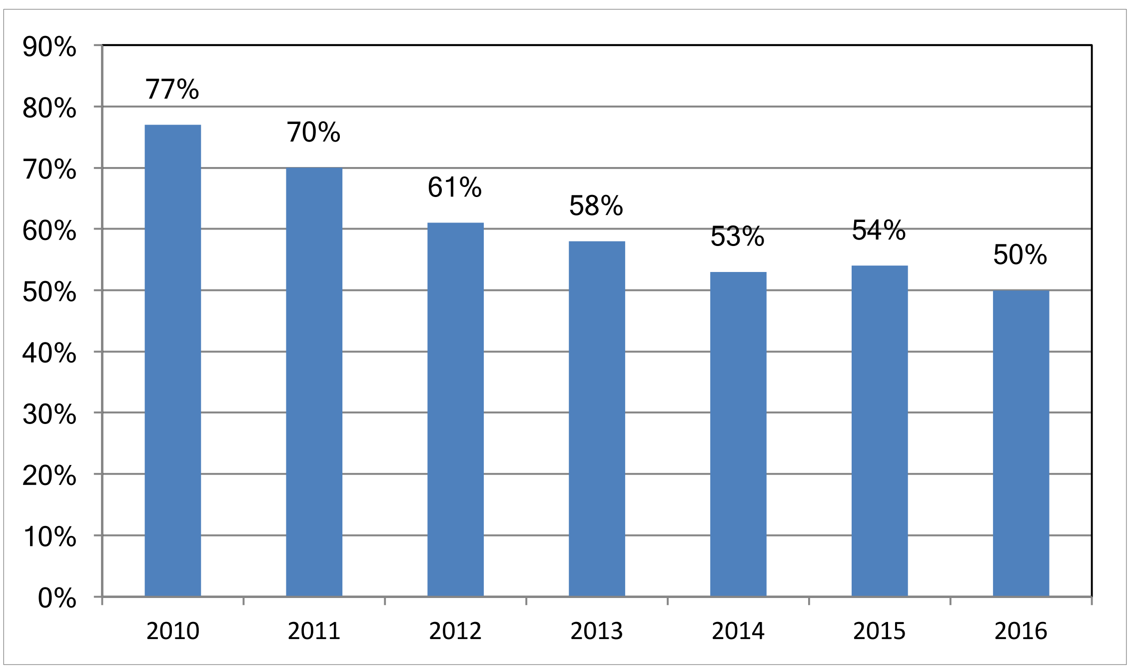

Figure 2.5 Drip coffee maker usage among coffee drinker in United States from 2011 to 2016 (National Coffee Association, 2016).

Coffee Flavor and Aroma

More than 1,500 distinct chemical compounds can be extracted from coffee beans, some of which create the complex flavor and aroma that we know as coffee (Hetzel, 2016). These compounds are volatile and non-volatile compounds that are contained both in the liquid matrix and the headspace aroma.

Bernheimer (1880) was the first to report the identification of some coffee volatiles, e.g. methylamine and pyrrole. The composition of the volatile fraction of coffee has been studied for years, and several hundreds of compounds have been identified as constituents of coffee aroma (Holscher, 1992; Sanz et al., 2001, 2002). Grosch (2008) reported that 841 compounds were found in coffee, including hydrocarbons (80), alcohols (24), aldehydes (37), ketones (85), carboxylic acids (28), esters (33), pyrazines (86), pyrroles (66), pyridines (20), other bases such as quinoxalines and indoles (52), sulphur compounds (100), furans (126), phenols (49), oxazoles (35) and others (20). Table 2.1 shows a list of the principal classes of volatile compounds identified in roasted coffee.

Table 2.1 Classes of volatile compounds identified in roasted coffee

Sulphur Compounds	Thiols
	Hydrogen sulphide
	Thiophenes (esters, aldehydes, ketones)
	Thiazoles (alkyl, alcoxy and acetal derivatives)
Pyrazines	Pyrazine itself
	Thiol and furfuryl derivatives
	Alkyl derivatives (primarily methyl and dimethyl)
Pyridines	Methyl, ethyl, acetyl and vinyl derivatives
Pyrroles	Alkyl, acyl and furfuryl derivatives
Oxazoles	
Furans	Aldehydes, ketones, esters, alcohols, acids, thiols, sulfides and in combination with pyrazines and pyrroles
Aldehydes and ketones	Aliphatic and aromatic species
Phenols	

(Buffo & Cardelli-Freire, 2004)

Volatile compounds influence the aroma of coffee which is responsible for all flavor attributes other than the basic taste attributes caused by nonvolatile compounds. Nonvolatile compounds consist of carbohydrates (sugar), proteins, peptides and free amino acids, polyamines and tryptamines, lipids, phenolic acids, trigoneline and various nonvolatile acids (Flament, 2002). Citric acid is known to give Kenyan coffee its lemony flavor. Lipids in coffee beans can never completely dissolve in the water and, along with soluble bean fibers, contribute to the texture of coffee, perceived as thickness or mouthfeel. Caffeine, coffee's most famous soluble content, dissolves easily in coffee, due to equal solubility in both water and oil. In the human body, this characteristic causes rapid permeation of the stomach lining, permitting direct entry into the bloodstream (Hetzel, 2016).

Although the aroma and flavor are characterized by the origin of green coffee, the roasting process controls the developmental progress of the volatile compounds as hundreds of chemical reactions take place simultaneously. Different roast degrees and conditions result in differences in complexity of coffee aroma. In general, roasting ruptures the cell structure of the green coffee beans, exposing it to heat that drives out the moisture and releases the aromatic compounds that have been chemically bound in the beans. The major reactions during roasting are Maillard reactions. Maillard reactions are reactions between nitrogen-containing substance like proteins, peptides, amino acids and reducing carbohydrate, hydroxyl-acids, phenols, forming aminoaldoses and aminoketones by condensation or Strecker degradation products. Strecker degradation is a reaction between an amino acid and α-dicarbonyl to the format of aminoketones which can condense to form nitrogen hetrocyclic compounds or can react with formaldehyde to form oxazoles. Other Maillard reactions include a breakdown of sulphur amino acids, for example, cysteine, cystine, and methionine, that are transformed into mercaptans, thiophenes, and thiazoles, or breakdown of hydroxy amino acids to form alkylpyrazines. Additionally, Millard reaction can include a breakdown of proline and hydroxyproline that can result in the formation of pyridines, pyrroles, and pyrrolyzines, degradation of trigonelline to form alkylpyridines and pyrroles, degradation of the quinic acid moiety to form phenols, degradation of pigments and degradation of minor lipid (Buffo, 2004).

Factors Influencing Coffee Flavor

Many factors influence the coffee flavor and aroma. Illy (2005) summarized that there are six factors that affect the sensory properties of coffee including growing regions and conditions, physiology, processing methods (from coffee cherries to green coffee bean), roasting levels, grinding size, and brewing methods.

Growth Regions and Conditions

Soil, climate, altitude and shade, all play important roles in creating a different coffee aroma and flavor profiles through influences on temperature, light availability, and water during ripening (Handayani, 2016). Elevation influences the fat and cholorogenic acid in *Arabica* coffee and rich volcanic soils produces acidic coffee (Leroy et al., 2006). Coffee that is grown in high altitude usually comes with high quality as higher altitudes increase berry ripe time resulting in a better tasting coffee bean (Nur et al., 2003). In general, Nur et al. (2003) stated that a temperature average of 16℃ to 20℃, relative humidity 75% to 95%, naturally precipitation of 2000mm to 3000 mm and rich nutrients in the volcanic soil are needed to produce high-quality coffee.

Physiology

Physiology changes happen during growth and development of coffee beans. Maturation indicated by color development from green to ripe has a strong influence on the coffee quality. For instance, green beans have lower quality grade than red ripe and over ripe beans (Leroy, 2006). Figure 2.6 shows the quality of coffee beans from green to over ripe. In the figure, it shows that quality improves during maturation and the highest quality accrues as silver skin disappears from the cell walls. Green beans lack the important aromatic development in the last stage of ripening (Illy, 2002). As the silver skin disappears from the cell wall a higher quality of coffee is achieved.

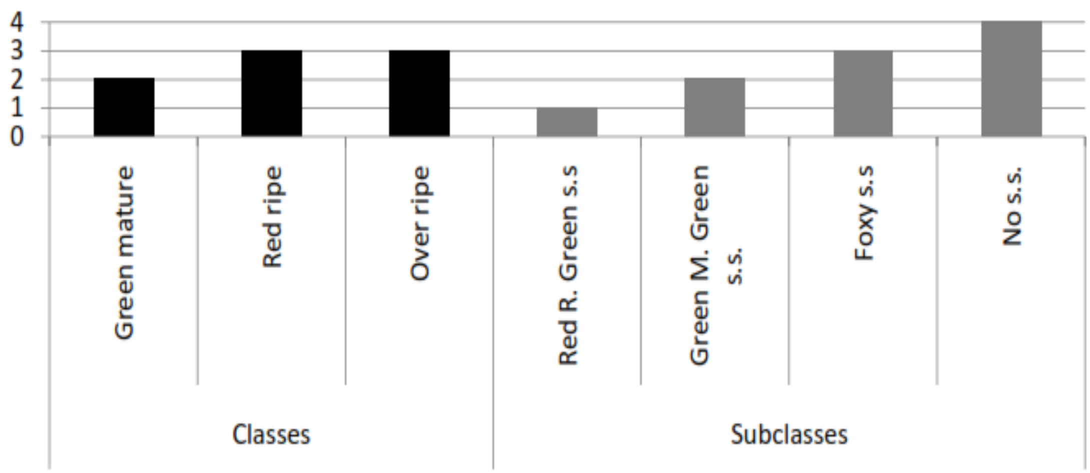

Figure 2.6 Quality grading of classes and subclasses (1= very low, 2=low, 3=good, 4= very good, s.s= silver skin; Handayani, 2016)

Harvesting

Harvesting usually involves traditional hand picking or mechanical harvesting. Traditional hand picking using husbandry labor produces the best quality of coffee by decreasing the defect percentage in coffee batches (Leroy, 2006). During hand picking, only ripe coffee should be picked while immature, overripe and raisin cherries should be separated. On the other hand, mechanical harvesting is more advantageous due to speed. Ethophon, a natural hormone, is applied to cherries before harvesting to unify maturity of cherries to make harvesting easier. In general, the yield depends on the harvest rod, speed, and frequency of rod vibration. Mechanically harvested cherries have varying maturity stages from raisin > overripe > red > green. Hand picking has been defined as a better harvesting method to provide the best coffee for processing (Handayani, 2016).

Picking

Picking or post-harvest was defined as either the dry methods or the wet methods. Dry methods are treatment consisting of drying coffee cherries to give husk coffee, followed by mechanical removal of the dried pericarp to produce green coffee or natural coffee. The wet method is a method of processing coffee cherries into dried parchment coffee. Treatments consist of mechanical removal of the exocarp in the presence of water, removal of all the mesocarp by fermentation or other methods, and washing followed by drying to produce parchment coffee (Batista, 2009). The wet method enhances the acidity of the coffee bean which interacts with the coffee body, while the dry method makes a sweet complex and heavy bodied coffee (Coffee Research Institute, 2006). All the process is important, however, once the beans have been harvested and prepared, the quality of the coffee is mostly influenced by the roasting process.

Roasting

The most significant development of flavors occurs during the roasting process. Roasting influences aroma and flavor of coffee. During roasting, at least 600 new volatile compounds that influence the aroma are produced. Handayani (2016) reported that green coffee has less volatile compounds than roasted coffee.

Brewing

The pleasant aroma released from roasted coffee beans during grinding are attractive as well as the aroma of freshly brewed coffee (Akiyama, 2003). However, because those fresh and pleasant aromas are highly volatile and unstable compounds, these are also easily lost easily during grinding (Akiyama, 2005). The International Coffee Organization (ICO) found that the concentration of acid compounds in final coffee is influenced by grind size. Larger grind size (particles size) produces a higher amount of acid compounds. Brewing temperature and time also influence coffee aroma and flavor. The optimum amount of acid was found during brewing at 94℃ and began to decrease when brew temperature was at 100℃ or higher. Parenti et al. (2014) showed that coffees brewed at lower temperatures had less aroma, flavor and body fullness, whereas coffees brewed at higher temperatures had higher burnt/roasted flavor. Brewing time of more than 5 minutes was found to reduce some acid compounds, but increased quinic acid content (responsible for unpleasant flavor). Holding coffee for longer than 20-30 minutes has been shown to develop sour or bitter tastes with smoky overtones (Handayani, 2016).

Gas Chromatography and Mass Spectrometry

Gas chromatography (GC) and mass spectrometry (MS) systems are used to identify volatile flavor and aroma compounds. The GC/MS system uses four steps to identify and quantify the volatile compounds: a collection of volatiles, separation of volatile compounds, identification of each compound, and quantification of each compound (Chambers & Koppel, 2013). The GC can separate volatiles into individual compounds while the MS can identify the compounds. This system identifies thousands of compounds although some might not be aromatic. Gas chromatography/olfactometry (GC/O) has been used to determine the most aromatic compounds that are likely to contribute to the characteristic aroma of brewed and ground coffee (Semmlroch, 1996; Czery et al., 1999). The volatiles is separated by the GC column and transported to the sniff port where they are combined with humidified air to prevent human nasal passages from drying out and sniffed by humans (Shahidi, 1994). Some studies of the headspace volatile compounds released from ground coffee used a gastight syringe to sample and GC/O to analyze the aromatic compounds (Holscher, 1992). Others used a static headspace sampler to investigate the effects of time and temperature on the volatile compounds released from roasted ground coffee (Sanz, 2001).

The volatiles are collected using solid phase microextraction (SPME) in the headspace of a container which then is injected into the GC/MS and desorbed. SPME involving both exposure to the gas phase above a sample and submersion in the liquid phase of a liquid sample has been applied to the flavor analysis of both brewed and ground coffee under static, no gas flow, conditions (Arthur, 1990; Roberts et al., 2000).

Extensive studies have been conducted since the beginning of the 1900s to discover the volatile compounds responsible for coffee aroma and flavor in roasted beans, ground coffee, and brewed coffee (Czerny et al., 1999; Sarrazin et al., 2000; Semmelroch & Grosch, 1996). Table 2.2 shows some aromatic compounds that have been identified in coffee and their corresponding odor description.

Coffee Terminology

Coffee is one of the most complex beverages that contains subtleties of aroma, flavor, and texture. The complexity of coffee makes it difficult to find the right vocabulary to describe all the sensory properties present. The coffee industry often uses experts to conduct a quality assessment of their coffee. The experts have long-standing experience with coffee and are trained to distinguish the small difference in coffee using vocabulary in various coffee wheels (SCAA, 2015a; Counter Culture Coffee, 2013). A coffee flavor wheel is one of the most iconic resources in the coffee industry and has been a standard resource in the industry for over two decades. These wheels express over 50 attributes that are commonly found in coffee.

The most commonly used method for testing coffee quality and defects is cupping. Coffee cupping is an efficient, professional test that determines both defect and coffee quality. The standard coffee cupping protocol usually involves visually inspecting the sample roast color, sniffing the dry ground, breaking the crust, deeply breathing the coffee aroma, re-smelling and tasting by slurping the coffee allowing it to spread to the back of the tongue (SCAA, 2015b). During the cupping, cuppers will fill rate specific coffee aspects, including fragrance/aroma, flavor, aftertaste, acidity, body, balance, uniformity, clean cup, sweetness, defects, and overall quality. Cuppers also need to give "tasting notes" to provide the word choice characteristics of the coffee. However, one disadvantage of cupping is that cuppers do not use a common language for flavor and aroma which may cause inconsistencies. Donforancese (2014) used four cuppers to score 13 coffees based on the Specialty Coffee Association of America "cupping protocol." A total of 59 terms were collected between the 13 coffees, and only four terms were used by more than two cuppers to describe a single cup of coffee.

A sensory lexicon is a set of words or attributes, used by the trained panel to describe sensory attributes in products during descriptive sensory analysis. It is widely used in all kinds of products, including both food/beverage categories as well as non-consumable products. A standardized lexicon provides a reliable and repeatable way to measure the flavor, texture, and aroma in a product by providing definitions and references (Lawless, 2013). In coffee, Seo (2008) found a total of 74 attributes out of 200 descriptors as representative terms of brewed coffee. These 200 descriptors were found from three sensory attributes sources: mass media, advertisements and literature (MAL) and consumer and trained panelists. A coffee sensory attribute pool was developed from these. Sixteen of 74 were unique sensory attributes specially influenced by Korean culture and linguistics. Hayakawa et al. (2010) produced a lexicon in Japan with a list of 127 terms (7 for appearance, 28 for overall, 61 for aroma, 23 for flavor and 8 for mouth feel) using six cuppers and four experienced coffee professionals. Kansas State University, Texas A&M University and World Coffee Research (WCR) developed a sensory lexicon for coffee where 108 attributes for flavor and aroma were identified (WCR, 2016).

The advantage of using a standardized lexicon is that it can prevent overlaps between terms when panelists try to describe a product during tasting, especially for a complex product like coffee. Additionally, the coffee lexicon provides a method for quantifying differences in aroma and flavor of coffee using standardized references and scales.

Table 2.2 Aromatic of roasted coffee

Chemical Category	Compounds	Odor Description
Acid	2-/3-Methylbutanoic acid	Sweaty[5,6] Acidlike[6]
	4-Methylbutanoic acid	Sweet/acid[1,2]
Alcohol	2-Furfuryl propanoate	Flowery, fruity[6]
	3-Mercapto-3-methylbutanol	Hazelnut/roasted[2] Meaty (broth)[5]
	Linalool	Flowery[5]
Aldehydes	2-Methylbutanal	Malty[5] Chocolate-like, fruity[6]
	2-(Methylthiol) propanal	Soy sauce[2]
	2- e 4-Methyl butanal	Buttery[2,3,4]
	3-Methylbutanal	Malty[5]
	3-Methylpropanal	Roasted cocoa[3]
	4-Hydroxy-3-methoxybenzaldehyde (Vaniline)	Vanilla[1,4,5]
	5-Ethyl-3-hydroxy-4-methyl-2(5H)-furanone	Seasoning-like[5]
	ρ-Anisaldehyde	Sweet, minty[5]
	Acetaldehyde	Fruity, pungent[5]
	Butanal	Chocolate, caramel[6]
	(E)-2-Nonenal	Buttery[2] Fatty[5]
	Hexanal	Butter rancid[3]
	Methional	Cooked potato[1,5]
	Methylpropanal	Malty/fruity[3,4,5]
	Octanal	Orangelike[6]
	Propanal	Roasted/fruity[3,4,5]
	Phenylacetaldehyde	Honey-like[5]
Ethers	2-/4-Methylanisole	Aniselike[6]
	Furfuryl methyl ether	Herbal, potato-like[6]
Ester	3-Mercapto-3-methyl butylformate	Catty, roasty[5]
Furan	2-Acetylfuran	Roasty, tobacco-like[6]
	2-(Methylthio-methyl)furan	Smoke/roasted[2]
Indole	3-Methylindole	Coconut[1]
Ketones	1-(1H-Pyrrol-2-yl)1-ethanone	Roselike[6]
	2-Ethyl-furaneol	Carame[1]
	2,3-Butanedione	Buttery, fruity, caramel-like[6]
	2-Ethyl-4-hydroxy-5-methyl-4(5H)-furanone	Sweet/caramel[2]
	2(5)-Ethyl-4-hydroxy-5(2)-methyl-3(2H)-Furanone	Caramel-like[5]
	2,5-Dimethyl-4-hydroxy-3(2H)-furanone(furaneol)	Caramel/sweet[1,2,4]

Table 2.2 Continued

Chemical Category	Compounds	Odor Description
Ketones	2,3-Butanedione	Buttery[1,2,3,4,5]
	2,3-Pentanedione	Oily-buttery[3,4,5] Buttery, caramel-like[6]
	3,5-Dihydro-4(2H)-thiophenone	Smoke/roasted[2]
	4-Hydroxy-2,5-dimethyl-3(2H)-furanone (HDF)	Caramel-like[5]
	4,5-Dimethyl-3-hydroxy- 2(5H)-furanone (sotolon)	Spicy[1,4] Seasoning-like[5]
	5-Ethyl-3-hydroxy-4-methyl-2(5H)-furanone (abhexon)	Spicy[1]
	β-Damascenone	Fruity[6]
	Dihydro-2-methyl-3(2H)-furanone	Dusty, musty[6]
	(E)-b-Damascenone	Honey-like, fruity[5]
Phenols	2-Methoxyphenol (guaiacol)	Phenolic/roasted[1,2,3,4,6] Burnt[6]
	4-Methoxyphenol	
	4-Ethyl-2-methoxyphenol (4-ethyl-guaiacol)	Phenolic[1,2,4]
	4-Vinil-2-methoxyphenol (4-vinil-guaiacol)	Cravo[1] Spicy[5]
	Guaiacol Phenolic	Burnt[5]
Pyrazines	2-Ethylpyrazine	Peanuts/roasted[3]
	2-Ethyl-3-methylpyrazine	Roasty, peanutlike[6]
	2-Methyl-3-trans-propenyl pyrazine	Roasty[6]
	2-Etenyl-3-ethyl-5-methylpyrazine	Earth[1,4]
	2-Etenyl-3,5-dimethylpyrazine	Earth[1,5] Roasty[5]
	2-Ethyl-3,5-dimethylpyrazine	Earth/hazelnut/roasted[1,2,3,4,6] potato-like[6]
	2-Methyl-3,5-diethylpyrazine	Roasty[6]
	2,3-Dimethylpyrazine	Hazelnut/roasted[2]
	2,3-Diethyl-5-methylpyrazine	Hazelnut/roasted[1,2,4,5]
	2,3-Diethyl-5,6-dimethylpyrazine	Roasty, cardboardlike
	2,5-Dimethylpyrazine	Hazelnut/roasted[2]
	2,6-Diethylpyrazine	Pyrazine, potato-like[6]
	2-Ethyl-6-methylpyrazine	Peanuts/roasted[3] Flowery, fruity[6]
	3-Isobutyl-2-methoxypyrazine	Earth[1,5]
	3-Isopropyl-2-methoxypyrazine	Earth[1,5]
	3-Ethyl-2,5-dimethylpyrazine	Earth[1]
	5-Methyl-5(H)-cyclopenta[b]pyrazine	Roasty, sweet[5]
	6,7-Dihydro-5H-ciclopentapyrazine	Hazelnut/roasted[2]

Table 2.2 Continued

Chemical Category	Compounds	Odor Description
Pyrazines	6,7-Dihydro-5-methyl-5H-ciclopentapyrazine	Hazelnut/roasted[2]
	Propylpyrazine	Herbal[6]
	Trimethylpyrazine	Roasty, earthy[5]
Pyrrole	1-(5-Methylfurfuryl)-pyrrole	pharmaceutical, roasty[6]
Sulfur compounds	2-Furfuryl methyl sulfide	Leatherlike[6]
	2-Furanmethanethiol	Smoke/roasted[2] Roasted[1,4] Roasty (coffee-like)[5]
	2-Methyl-3-furanthiol	Meaty, boiled[5]
	2-Methyl-4-furanthiol (furfuryl mercaptan)	Meat[1,4]
	3-Methyl-2-buten-1-thiol	Amine-like[5]
	4-Methyl-2-buteno-1-thiol	Smoke/roasted[2,4]
	5-Dimethyl-trisulfide	Sulfur[1,4]
	Bis(2-methyl-3-furyl)disulphide	Meaty, sweet[5]
	Methanethiol (mercaptan)	Cooked potato[3,4] Cabbage-like[5]
Thiazole	2-Acetyl-2-thiazoline	Roasted[1]
	5-Ethyl-2-methylthiazole	Rubberlike[6]
	5-Ethyl-2,4-dimethylthiazole	Earthy, roasty[5]
	Dimethyltrisulfide	Cabbage-like[5]Putrid, unpleasant[6]
	Trimethylthiazole	Roasty, earthy[5]

1.Sanz, 2002; 2.Akiyama, 2005; 3.Maeztu, 2001; 4.Czerny, 1999; 5.Holscher, 1990; 6.Lopez-Galilea, 2006.

Research Objectives

The major objective of this research was to test the influence of different coffee types and brew methods on coffee aroma and flavor. In order to do that, four different types of standard coffee grounds from Folgers® Coffee were used, and each coffee was brewed using four preparation methods that are commonly used by consumers to brew coffee. In order to test the differences, a descriptive aroma and flavor attributes panel that has been trained on the WCR Coffee Lexicon using a 0-15 point intensity scales was used. There are 108 attributes characterized in the lexicon, but only 35 of the main attributes were evaluated. Coffee pH and total dissolved solids were determined as indications of the acidity and the extraction level of the coffee. A gas chromatography (GC) and mass spectrometry (MS) system with a sniff port were used to identify aroma events and the volatile flavor and aroma compounds of the brewed coffee as affected by the coffee types and brew methods.

CHAPTER III

MATERIALS AND METHODS

Sample Collection

Commercial blends of Folgers® coffee were selected to differ in roast level (mild, medium, medium-dark and dark) and were purchased commercially. Three different production lots of each roast level were used. Each roast type was chosen to vary in flavor. Folgers® Breakfast blend, Classic roast, 100% Colombia and Black silk were chosen to represent mild, medium, medium dark and dark roast, respectively. Each roast type was prepared to utilize four different coffee brew methods (drip brew, French press, cold brew, and pour over). The coffee to water ratio was 6.7 g of coffee grounds per 170 mL of water. All the brew methods used 47.3 g coffee grounds and 1.2 L of double distilled, deionized water for brewing.

For the drip brew, weighed coffee grounds were placed into a paper filter (Hill Country Fare, 8-12 cup/1900-2900mL basket size, San Antonio, TX) and transferred to the coffee maker filter basket (Mr. Coffee Programmable Coffee Maker, Model 2003398, capacity 12 cups, Boca Raton, FL). Then room temperature double distilled, deionized water was poured into the reservoir and began brewing. In the French press method, weighed coffee grounds were transferred into the French press coffee maker (Bodum French Press Brazil Coffee Maker, no. 1552, capacity 12 cups/2900mL, Portuguesa SA, Portugal). Boiling water (100 °C) was slowly poured over the grounds in a circular motion. After the coffee had been steeped for 3 minutes, the strainer was slowly pushed down to filter the coffee. For cold brewed coffee, weighed coffee grounds was placed in a Toddy Cold Brew System (Toddy, LLC) with a filter snuggly in the bottom and a rubber stopper underneath it for the Cold Brew method. Then room temperature water was poured over the grounds. After the water and the grounds were stirred thoroughly to ensure no dry grounds were present, the system was placed into a 4 °C refrigerator for 24 hours. After 24 hours, the stopper was removed to filter the coffee into a 1.5 L glass mason jar. Before serving, the mason jar was placed in a water bathed until the coffee temperature reaches 170 °F (77 °C). In the pour over method, weighed coffee grounds were put into the metal pour over the filter (Bodum Pour Over Coffee Maker, no. 11593, capacity 51 oz/1500 mL, Portuguesa SA, Portugal) and boiling water (100 °C) was slowly poured over the grounds.

After brewing, the coffee was poured into a preheated thermo jugs (Oggi™ Pumpmaster, 3L, model no. 6538, Anaheim, CA). In order to control the serving temperature of the coffee, iron-constantan thermocouples (Omega Engineering, Stanford, CT) were used. The coffee was cooled down to 150 °F (66 °C), after which the pump was put into place, and the lid was closed and sealed to prevent further temperature changes.

Each roasted coffee by brew method sample was analyzed in triplicate within a replicate. A replicate was defined as a different manufactured lot of coffee within each coffee type. All the samples were presented monadically and coded with 3-digit random numbers.

Descriptive Aroma and Flavor Sensory Evaluation

A total of 144 brewed coffee samples were evaluated by a trained coffee descriptive attribute panel with 200 hours of training using the WCR Coffee Lexicon. Coffee aroma and flavor attributes were measured using a 16 point scale within the lexicon (from 0-15, where 0 = none and 15 = extremely intense) for 25 aroma attributes and 35 flavor & texture attributes. On each testing day, panelists had access to references used in the WCR Coffee Lexicon, and the panelists calibrated using one orientation or "warm up" sample that was evaluated, discussed orally and the consensus was obtained. Panelists were seated in the evaluation room separated from the sample preparation area around a rectangular table with florescent lighting with a room temperature of 72 °F (22 °C). After evaluation of the orientation sample, panelists were served the first sample of the session and asked to individually rate the sample for each coffee lexicon attribute. Each sample was served using an 8 oz double wall glass cup (Bodum, Model Number 4556-10, Portuguesa SA, Portugal) with a glass watch on the top. Glass cups and watch tops all were pre-washed, double rinsed with double distilled, deionized water and preheated at 38 °C for 30 minutes prior to use. Panelists slid the watch glass slightly from the top and smelt the coffee two times to score the aroma attributes. Between each aroma evaluation, panelists were encouraged to sniff their hand to clean their nasal passages. After aroma evaluation, panelists tasted the coffee for flavor and texture attribute determinations. Freshly cut Granny Smith apples, HEB plain bagel, and double distilled, deionized water was used to clean the palate between samples. Panelists were allowed multiple sampling if needed and the coffee was held at 120 °F (62 °C) and available for resampling. During the evaluation, panelists were not allowed to talk. Five samples were presented individually each sensory day. After evaluation, panelists discussed the aroma and flavor attributes and came to consensus on the intensity of each attribute. The panel leader recorded the final score. Treatments were randomly assigned to a sensory day.

Headspace-SPME-GC/MS

Volatiles were captured from the same coffee evaluated by the descriptive panelists. From samples prepared for trained panelists, approximately 100 mL of coffee sample was analyzed on gas chromatography/ mass spectrometry (GC/MS). When the coffee had finished brewing, coffee samples were immediately poured into glass jars (473 mL) with a Teflon lid under the metal screw-top to avoid off-aromas. The headspace was collected with a solid phase microextraction (SPME) portable field sampler (Supelco 504831, 75µm carboxy/ polydimethylsiloxane, Sigma-Aldrich, St. Louis, Mo) when the jar had sat at room temperature for 2 h.

The SPME was stored at - 80 °C until volatile analysis. Volatiles were evaluated using the Aroma Trax gas chromatograph space (GC)/ mass spectrophotometer (MS) system (Agilent Technologies 7920 series GC, Sanata Clara, CA) with dual sniff ports for characterization of aromatics. This technology separated individual volatile compounds, identified their chemical structure and characterized the aroma/flavor associated with the compound. Only aromatic compounds were evaluated.

Chemical Analysis

The pH of each coffee sample was measured in triplicate using a pH probe (SPH70P portable pH meter, VWR International AG, Switzerland) after the temperature of the coffee samples cooled down to 50 °C and 20 °C. The pH probe was calibrated daily using standard solutions at pH 4.0 and 7.0.

A total of 10 g of coffee extract was dried at 105 °C for 24 hours until constant weight (less than ± 0.5 mg) to measure total dissolved solids (TDS). The extraction level of the coffee after brewing was measured at 20 °C using a refractometer (ATAGO Pocket Refractometer, PAL, Japan) for the percentage brix value. All the measurements were done in triplicate.

Statistical Design

The trained panel descriptive aroma and flavor attributes, volatile aromatic compounds, pH, TDS, and extraction level were analyzed using Analysis of Variance as a 4 x 4 x 3 factorial arrangement where four coffee types by four brew methods were defined as main effects. Three replicates were included as a block. An $\alpha < 0.05$ was used for all analyses. Main effects, two-way interactions, and blocks were defined in the initial model. Main effects, blocks and significant two-way interactions were included in the final model. Least square means were calculated for main effects, and significant two-way interactions and differences between significant least square means were determined using the pdiff function of SAS (v.9.4, SAS Institute, Inc., Cary, NC). Principal component and partial least squares regression analysis (XLSTAT, Microsoft, Redman, WA) were used to understand relationships between chemical, volatile aromatic compounds, and trained sensory aroma and flavor descriptive attributes among different coffee types and brew methods. These data were presented as biplots.

CHAPTER IV

RESULTS AND DISCUSSION

Expert, Trained Descriptive Coffee Attributes Analysis

The coffee attributes, definition and reference standards used in this study were outlined in Table 4.1 (WCR, 2016). Sixty attributes were tested including 25 aromas, and 35 flavor and texture descriptive attributes. Descriptive sensory attributes were evaluated using a 16 point scale (where 0 = none and 15 = extremely intense). Aroma attributes for smoky, woody, cocoa, caramelized, fruity-dark, fruity-no citrus, floral, dark green, nutty, beany, petroleum-like, stale, and moldy/damp and flavor attributes for smoky, woody, grain, caramelized, fruity-dark, fruity-berry, fruity-no citrus, floral, dark green, nutty, beany, petroleum-like, stale, and moldy/damp were either not found or the least square means were < 0.1 in the tested coffee samples. Data for these attributes were not presented.

Coffee Types and Brew Methods Interactions

The hypothesis that different brew methods will not induce differences in the descriptive flavors and aromas of four commercial coffees was rejected. Interactions were reported for three attributes (Table 4.2). Additionally, overall impact tended to differ (P = 0.056) between coffee types and brew methods. Cold brew coffee tended (P = 0.056) to have the lowest overall impact. Coffee with higher roast levels (Folgers®

Classic roast, Folgers® 100% Colombia and Folgers® Black silk) prepared using the French press method and Folgers® Black silk and Folgers® 100% Colombia coffees prepared using the drip method had a higher (P = 0.056) overall impact. Coffee prepared using the pour over method was intermediate in overall impact. Overall impact was defined as the maximum overall sensory impression during the tasting. These results indicated that the level of roast affected overall sensory impression in combination with brewing method.

Three attributes, mouth drying/astringent, thickness and roasted, had significant (P < 0.05) interactions between coffee types and brew methods (Table 4.2). For the 4 coffee types, the cold brewed coffee was thinner and had less roasted flavor than coffee prepared in the other three brew methods (P < 0.05). The thickest coffee was from Folgers® Classic roast coffee prepared using the French press method, and Folgers® Black silk coffee prepared using either the drip method, French press method or pour over method. Other coffees and brew methods were intermediate in thickness, while differences were slight, within 0.2 to 0.1, and consistent differences were reported. Thickness was defined as the amount of solids extracted from a coffee during brewing. Total dissolved solids (%, TDS) were determined and will be discussed later.

For mouth drying/astringent, the cold brewed coffee and Folgers® Classic roast pour over coffee were the lowest (P < 0.01). Folgers® 100% Colombia coffee prepared using the drip method was highest (P < 0.01) in mouth drying/astringent. Other coffees and brew methods were intermediate in mouth drying/astringent. Mouth drying/astringent has been defined as a drying puckering sensation on the surface and/or edge of the tongue and mouth. These results indicated that brewing methods and coffee types affected the drying feeling in the mouth and tongue.

For roasted flavor aromatics, coffee prepared using the cold brew method had the lowest roasted flavor aromatics. Coffee with a higher roasted level (Folgers® 100% Colombia and Folgers® Black silk) prepared using the French press method and the drip method, Folgers® Black silk prepared using the pour over method and Folgers® Classic roast prepared using French press method had higher ($P < 0.05$) roasted flavor aromatics. Other coffees and brew methods were intermediate in roasted flavor aromatics. Roasted flavor has been defined as a dark brown impression characteristic of products cooked to a high temperature by dry heat. These results indicated that level of roast affected the dark brown impression characteristic of coffee in combination with brewing method and the cold brew method did not effectively ($P > 0.05$) bring out the roast flavor aromatics of coffee. The result was similar to Sanchez et al. (2015) who reported that roasted flavor differed across brew methods (cupping, drip, espresso and French press) using three different coffee beans (Las Brisas, Los Andes, and Porvenir).

Table 4.1 Definition and references for coffee descriptive attributes and their intensities (0 = none; 15 = extremely intense, WCR, 2016)

Attributes	Definition	Reference
Acrid	The sharp, pungent, bitter, acidic aromatics associated with products that are excessively roasted or browned.	Wright's Liquid Smoke = 9.5 (a) Alf's Red Wheat Puffs = 3.0 (a), 3.0 (f)
Aftertaste	The taste intensity of food or beverage that is perceived immediately after that food or beverage is removed from the mouth.	Bitter Aftertaste Sour Aftertaste Astringent Aftertaste
Ashy	Dry, dusty, dirty, smoky aromatics associated with the residual of burnt products.	Gerkens Midnight Black (BL80) cocoa Powder = 2.5 (a), 3.5(f)
Beany	Aromatic characteristic of beans and bean products includes musty/earthy, musty/dusty, sour aromatics, bitter aromatics, starchy and green/pea pod, nutty or brown.	Bush Pinto Beans (canned) = 7.0 (a), 7.5 (f)
Bitter	The foundational taste factor associated with a caffeine solution.	0.02% Caffeine Solution = 3.5 0.035 % Caffeine Solution = 5.0 0.05% Caffeine solution = 6.5 0.06% Caffeine solution = 8.5 0.07% Caffeine solution = 10.0 0.10 % Caffeine solution = 12.0
Blended	The melding of individual sensory notes such that the products present a unified overall sensory experience as opposed to spikes or individual notes.	Folgers Classic Roast Instant coffee crystals=3.0(f) Folgers Classic Roast Ground Coffee = 6.0(f) Gevalia Kaffe Traditional Roast Ground medium coffee=10.0(f)
Body/Fullness	The foundation of flavor notes that gives substance to the product. The perception of robust flavor that is rounded with the body.	Folgers Classic Roast instant coffee crystals=5.0(f) Folgers Classic Roast Ground Coffee (brewed) = 7.5(f) Gevalia Kaffe Traditional Roast ground medium coffee=10.0(f)

Table 4.1 Continued

Attributes	Definition	Reference
Burnt	The dark brown impression of an over-cooked or over-roasted product that can be sharp, bitter and sour.	Alf's Red Wheat Puffs (2 pieces in the mouth) = 3.0 (f); 8.0 (a) Over Roasted Peanuts/Burnt =7.5 (f)
Caramelized	A round full bodied, medium brown sweet aromatic associated with cooked sugars and other carbohydrates. Does not include burnt or scorched notes.	Le Nez du café` n. 25 'caramel' = 8.0 (a) C&H Golden brown sugar in water = 2.5 (f)
Cardboard	The aromatic associated with cardboard or paper packaging.	Cardboard = 7.5 (a)
Cocoa	A brown, sweet, dusty, musty, often bitter aromatic associated with cocoa bean, powdered cocoa, and chocolate bars.	Hershey's Cocoa Powder in water = 7.5 (a), 5.0 (f)
Dark Chocolate	A high intensity blend of cocoa and cocoa butter that may include dark roast, spicy, burnt, must notes which includes increased astringency and bitterness.	Lindt Excellence Dark Chocolate bar 90% cocoa = 6.0 (a), 11.0 (f)
Dark Green	The aromatics commonly associated with cooked green vegetables such as spinach, kale, green beans that may include bitter, sweet, dusty, musty, earthy, and may have a dark, heavy impression.	Green Giant Green beans water=5.0 (a), 6.0 (f)
Floral	Sweet, light, slightly fragrant aromatic associated with (*fresh*) flowers.	Carnation essence oil = 7.5 (a) Diluted Welch's White Grape juice, diluted 1:1 = 5.0 (f), 6.0 (a) Le Nez du café` n.12 'coffee blossom' = 8.0 (a)
Fruity, berry	The sweet, sour, floral, sometimes heavy aromatic associated with a variety of berries such as blackberries, raspberries, blueberries, strawberries	Welch's Farmers Pick Black berry juice = 7.5 (f)

Table 4.1 Continued

Attributes	Definition	Reference
Fruity-Dark	An aromatic impression of dark fruit that is sweet and slightly brown associated with dried plums and raisins.	Diluted Sunsweet prune juice = 4.5 (f); 3(a)
Fruity, non-citrus	A sweet, lightly fruity, somewhat floral, sour, or green aromatics which may include – apples, grapes, peaches, pears, cherry	Welch's white grape juice diluted (1:1) = 6.5 (a), 5.5 (f) Le Nez du café n.17 'apple' = 7.0 (a)
Grain	Light brown, dusty, musty, sweet aromatics associated with grains.	Cereal Mix (dry) = 8.0 (f), 5.0 (a)
Mouth Drying /Astringent	A drying puckering or tingling sensation on the surface and/or edge of the tongue and mouth.	0.05% Alum Solution = 2.5 0.07% Alum Solution = 3.5
Musty/dusty	The aromatics associated with dry closed air spaces such as attics and closets. May be dry, musty, papery, dry soil or grain.	Kretschner Wheat Germ = 5.0 (a)
Musty/earthy	Somewhat sweet, heavy aromatics associated with decaying vegetation and damp black soil.	Le Nez du café` n.1 'earthy' = 12.0 (a) Miracle Soil Potting soil = *9.0 (a)*
Nutty	A combination of slightly sweet, brown, woody, oily, musty, astringent, and bitter aromatics commonly associated with nuts, seeds, beans, and grains。	Mixture of Diamond Sliced Almonds and Diamond Shelled Walnuts = 7.5 (f) Le nez du café n. 29 'roasted hazelnuts' = 7.5 (a)
Overall impact	The maximum overall sensory impression during the whole tasting time.	Gevalia Kaffe Traditional Roast ground medium coffee=7.5(f) Folgers Classic Roast Ground Coffee = 9.0(f) Folgers Classic Roast instant coffee crystals=12.0(f)
Overall Sweet	The perception of a combination of sweet taste and aromatics.	Nabisco Lorna Doone Cookie = 5.0 (f)

Table 4.1 Continued

Attributes	Definition	Reference
Petroleum-like	A specific chemical aromatic associated with crude oil and its refined products that have heavy oil characteristics。	Vaseline Petroleum Jelly = 3.0 (a)
Roasted	Dark brown impression characteristic of products cooked to a high temperature by dry heat. Does not include bitter or burnt notes.	Roasted peanuts 3 min = 2.0 (f) Roasted peanuts 7 min = 4.0 (f) Roasted peanuts 9 min = 8.0 (f) Roasted peanuts 13 min = 11.0 (f) Le Nez du café` n. 34 'roasted coffee'=7.5 (a)
Smoky	An acute pungent aromatic that is a product of combustion of wood, leaves or non-natural product.	Diamond Smoked Almonds = 6.0 (a), 5.0 (f)
Sour	The fundamental taste factor associated with a citric acid solution.	0.015% Citric Acid Solution = 1.5 0.05% Citric Acid Solution = 3.5
Sour Aromatics	An aromatic associated with the impression of a sour product.	Bush Pinto Beans (canned) = 2.0 (a)
Stale	The aromatics characterized by a lack of freshness.	Mama Mary's Pizza Crust = 4.5 (a), 4.0 (f)
Sweet	A fundamental taste factor of which sucrose is typical.	1% Sucrose Solution = 1.0
Sweet Aromatics	An aromatic associated with the impression of a sweet substance.	Lorna Done = 5.0 (f)
Thickness	The thick feel of the beverage as you press your tongue through it.	5% sucrose solution = 2.0 Campbell's Tomato Juice = 4.0
Woody	The sweet, brown, musty, dark aromatics associated with a bark of a tree.	Diamond Shelled Walnuts = 4.0 (f), 4.0(a)

[a] f = flavor, a=aroma

Table 4.2 Least square means for flavor descriptive sensory attributes for brew methods and coffee types interactions.

Treatment	Overall Impact	Mouth drying /Astringent	Thickness	Roasted
P value	0.05	0.0008	0.04	0.02
Breakfast*Cold [h]	6.3^{g}	1.6^{ef}	1.3^{e}	4.8^{d}
Breakfast*Drip [h]	9.1^{bcd}	2.0^{cd}	2.0^{cd}	7.4^{b}
Breakfast*French [h]	8.4^{de}	1.9^{cde}	1.9^{cd}	7.2^{b}
Breakfast*Pour [h]	8.9^{cd}	2.1^{c}	1.9^{cd}	7.3^{b}
Classic*Cold [h]	6.2^{g}	1.6^{ef}	1.2^{e}	5.2^{d}
Classic*Drip [h]	9.2^{bcd}	2.2^{bc}	1.9^{cd}	7.2^{b}
Classic*French [h]	9.7^{abc}	2.0^{cd}	2.4^{a}	7.6^{ab}
Classic*Pour [h]	7.8^{ef}	1.7^{def}	1.9^{d}	6.2^{c}
Colombia*Cold [h]	6.4^{g}	1.7^{def}	1.3^{e}	5.1^{d}
Colombia*Drip [h]	10.4^{a}	3.1^{a}	2.0^{cd}	7.8^{ab}
Colombia*French [h]	10.0^{ab}	2.6^{b}	2.1^{bcd}	7.8^{ab}
Colombia*Pour [h]	8.2^{de}	1.9^{cde}	2.2^{abc}	6.2^{c}
Black*Cold [h]	7.0^{fg}	1.3^{f}	1.3^{e}	5.3^{d}
Black*Drip [h]	10.4^{a}	2.6^{b}	2.2^{abc}	8.2^{a}
Black*French [h]	9.9^{abc}	2.1^{c}	2.2^{abc}	7.9^{ab}
Black*Pour [h]	8.9^{cd}	2.0^{cd}	2.3^{ab}	7.8^{ab}

[abcdfg] Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[h] Breakfast = Folgers® Breakfast blend, Classic = Folgers® Classic roast, Colombia = Folgers® 100% Colombia, Black = Folgers® Black silk, Cold = cold brew, Drip = drip brew, Pour = pour over, French = French press
[i] P value from Analysis of Variance table

Differences Among Coffee Types

Least square means of aroma and flavor descriptive sensory attributes were affected by coffee blends (Table 4.3). Sweet aroma, fruity berry aroma, overall impact, blended, mouth drying/astringent, sweet, sour and bitter basic taste, roasted, burnt, overall sweet, acrid and bitter, sour, and astringent aftertaste differed ($P < 0.05$) across coffee blends.

Other aroma attributes did not differ ($P > 0.05$) in intensity level across coffee blends except sweet and fruity berry. Bhumiratana (2011) found that in brewed coffee, coffee, roasted, burnt/acrid and ashy/sooty aroma attributes increased across roasting levels, especially in dark roasted coffee. Folgers® 100% Colombia coffee was the highest ($P < 0.05$) for sweet and fruity berry aroma. These results disagreed with Bhumiratana (2011) who reported that sweet aroma was at the highest intensity in the light roasted coffee. In Bhumiratana (2011), light roasted coffee generally yielded higher cocoa and nutty aroma notes while dark roasted coffee yielded more pungent, sour aromatics. However, Bhumiratana (2011) used wet process green Arabica coffee beans that were different from this research.

As expected, coffee with higher roasted levels (Folgers® 100% Colombia and Folgers® Black silk) had higher ($P < 0.05$) levels of overall impact, bitter and sour basic taste, burnt, acrid, bitter aftertaste, sour aftertaste and astringent aftertaste than the other two treatments. Folgers® Breakfast blend had the lowest ($P < 0.05$) level of sour basic taste. Folgers® 100% Colombia coffee was highest ($P < 0.05$) in mouth drying/astringent and sweet basic taste. Folgers® Black silk coffee had the highest level ($P < 0.05$) of roasted, acrid and sour basic taste. When the roast level increased, the intensity of overall impact, burnt, acrid, sour basic taste and bitter aftertaste increased. Czerny et al. (1999) reported that roasted, earthy, and smoky attributes increased with the degree of roasting. Akiyama et al. (2008) also showed that smoke/roast, sweet/caramel, and green were positively correlated with the degree of roasting, while sweet/fruity and acidic attributes were negatively correlated.

Differences Among Brew Methods

Least square means of aroma and flavor descriptive sensory attributes were affected by brew methods (Table 4.4). Among four brew method treatments (cold brew, drip brew, French press, and pour over), coffee from the cold brew method differed in sensory attributes from coffee prepared using the other methods. Cold brewed coffee was lowest ($P < 0.05$) in roasted, burnt and ashy aroma attributes; overall impact, body/fullness, and thickness attributes; roasted, burnt, ashy, acrid, and musty/earthy flavor attributes; bitter and sour basic tastes; and bitter and sour aftertaste, but highest ($P < .0001$) in sweet and fruity berry aroma, overall sweet and sweet basic taste than coffee from the other three brew methods. Pour over brewed coffee was intermediate in sensory attributes, except musty/dusty aroma when compared to coffee from the other brewing methods.

Coffee from the four brew methods differed ($P < .0001$) in bitter basic taste, burnt flavor aromatic and bitter aftertaste. Coffee from the drip brew method was the highest bitter basic taste, burnt flavor aromatic and bitter aftertaste while coffee from the cold brew method was lowest in these attributes. Coffee from the French press and pour over methods were intermediate in these attributes. Illy (2002) reported that soluble compounds, such as acids and caffeine, are more prominent in coffee when the coffee is prepared using the drip brew methods as the aforementioned compounds have the opportunity to solubilize into the liquid during brewing.

Drip brewed and French press brewed coffee had higher ($P < .0001$) roasted, burnt and sour aromas; overall impact and astringent; roasted flavor aromatics; sour basic taste; and sour aftertaste than cold brewed and pour over brewed coffee. Gloess et al. (2013) found that drip and French press coffee were characterized by a modest aromaticity, a relatively weak roasty and bitter flavor, and a more pronounced level of sweetness than coffee from other brewing methods (espresso, nespresso, bialetti).

Drip brewed, and French press brewed coffee were similar in many attributes but differed ($P < .0001$) in mouth drying/astringent, burnt flavor aromatics, bitter basic taste and bitter aftertaste. Gloess et al. (2013) reported that the flavor profile of French press coffee was well balanced while drip brewed coffee was low but had a well-balanced profile as an after-sensation. In this study, French press was slightly higher in blended flavor than coffee from the drip brew method.

Table 4.3 Least square means for aroma and flavor descriptive sensory attributes for four commercial coffee blends.

Attributes		Commercial Coffee Blends[d]				
	P value[e]	Breakfast[d]	Classic[d]	Colombia[d]	Black[d]	RMSE[f]
Aroma						
Roasted	0.21	6.4	6.3	6.5	6.7	0.92
Burnt	0.07	1.4	1.6	1.6	1.8	0.68
Sweet	0.008	0.6^{ab}	0.5^{b}	0.8^{a}	0.4^{b}	0.51
Sour	0.54	1.0	1.1	1.1	1.1	0.41
Ashy	0.82	0.9	0.8	0.8	0.9	0.43
Acrid	0.08	0.1	0.0	0.1	0.2	0.30
Musty/earthy	0.80	0.1	0.1	0.1	0.2	0.37
Grain	0.40	0.2	0.2	0.1	0.1	0.38
Dark Chocolate	0.28	0.5	0.5	0.4	0.3	0.52
Fruity, Berry	0.04	0.1^{b}	0.1^{b}	0.4^{a}	0.1^{b}	0.50
Cardboard	0.10	0.4	0.2	0.1	0.3	0.45
Musty/dusty	0.06	0.4	0.2	0.3	0.1	0.44
Flavor						
Overall Impact	0.001	8.2^{b}	8.2^{b}	8.8^{a}	9.1^{a}	1.08
Blended	0.002	7.8^{a}	7.4^{ab}	6.9^{b}	7.1^{b}	1.05
Body/Fullness	0.23	7.2	7.0	7.1	7.4	0.78
Mouth drying/ Astringent	<.0001	1.9^{b}	1.9^{b}	2.3^{a}	2.0^{b}	0.44
Thickness	0.07	1.8	1.8	1.9	2.0	0.29
Roasted	0.001	6.7^{b}	6.6^{b}	6.7^{b}	7.3^{a}	0.83
Bitter	0.02	6.2^{b}	6.5^{ab}	7.1^{a}	7.0^{a}	1.31
Burnt	0.004	1.8^{b}	2.1^{ab}	2.3^{a}	2.4^{a}	0.69
Overall Sweet	0.009	0.5^{a}	0.4^{ab}	0.6^{a}	0.3^{b}	0.45
Sweet	0.006	0.6^{ab}	0.40^{b}	0.7^{a}	0.3^{c}	0.46
Sour	0.0007	2.0^{c}	2.3^{bc}	2.5^{ab}	2.6^{a}	0.61
Ashy	0.24	1.3	1.3	1.4	1.6	0.61
Acrid	0.01	0.1^{b}	0.2^{b}	0.3^{ab}	0.4^{a}	0.46
Musty/earthy	0.74	0.3	0.2	0.2	0.3	0.44
Dark Chocolate	0.74	0.6	0.8	0.7	0.6	0.74
Cocoa	0.59	0.3	0.1	0.2	0.1	0.45
Musty/dusty	0.60	0.2	0.2	0.2	0.1	0.40
Bitter Aftertaste	0.01	3.0^{b}	3.0^{b}	3.3^{ab}	3.4^{a}	0.72
Sour Aftertaste	0.0003	2.0^{b}	2.0^{b}	2.5^{a}	2.4^{a}	0.60
Astringent Aftertaste	0.006	1.7^{b}	1.7^{b}	2.1^{a}	2.0^{ab}	0.56

[abc] Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[d] Breakfast = Folgers® Breakfast blend, Classic = Folgers® Classic roast, Colombia= Folgers® 100% Colombia, Black = Folgers® Black silk
[e] P value from Analysis of Variance table
[f] RMSE = Root Mean Square Error

Table 4.4 Least square means for aroma and flavor descriptive sensory attributes for four brew methods.

Attributes		Brew Method[e]				
	P value[f]	Cold[e]	Drip[e]	French[e]	Pour[e]	RMSE[g]
Aroma						
Roasted	<.0001	5.4[c]	7.0[a]	7.1[a]	6.5[b]	0.92
Burnt	<.0001	0.94[c]	2.0[a]	2.0[a]	1.4[b]	0.68
Sweet	<.0001	1.1[a]	0.3[c]	0.4[bc]	0.5[b]	0.51
Sour	0.002	0.9[b]	1.2[a]	1.2[a]	0.97[b]	0.41
Ashy	<.0001	0.6[b]	1.1[a]	1.0[a]	0.6[b]	0.43
Acrid	0.28	0.1	0.1	0.2	0.1	0.30
Musty/earthy	0.05	0.0	0.2	0.2	0.2	0.37
Grain	0.08	0.3	0.1	0.1	0.1	0.38
Dark Chocolate	0.24	0.4	0.3	0.5	0.5	0.52
Fruity, Berry	<.0001	0.53[a]	0.0[b]	0.1[b]	0.0[b]	0.50
Cardboard	0.84	0.2	0.3	0.3	0.3	0.45
Musty/dusty	0.02	0.1[b]	0.2[b]	0.3[ab]	0.4[a]	0.44
Flavor						
Overall Impact	<.0001	6.5[c]	9.8[a]	8.8[a]	8.4[b]	1.08
Blended	<.0001	8.1[a]	6.4[b]	6.9[b]	7.8[a]	1.05
Body/Fullness	<.0001	5.8[b]	7.6[a]	7.7[a]	7.4[a]	0.78
Mouth drying/ Astringent	<.0001	1.9[b]	1.9[b]	2.3[a]	2.0[b]	0.44
Thickness	<.0001	1.3[b]	2.0[a]	2.2[a]	2.1[a]	0.29
Roasted	<.0001	5.1[c]	7.7[a]	7.6[a]	6.9[b]	0.83
Bitter	<.0001	5.3[d]	8.0[a]	7.3[b]	6.2[c]	1.31
Burnt	<.0001	1.2[d]	2.9[a]	2.5[b]	2.1[c]	0.69
Overall Sweet	<.0001	0.9[a]	0.2[b]	0.3[b]	0.4[b]	0.45
Sweet	<.0001	1.0[a]	0.2[b]	0.3[b]	0.5[b]	0.46
Sour	<.0001	1.7[c]	2.8[a]	2.6[a]	2.2[b]	0.61
Ashy	<.0001	0.9[c]	1.8[a]	1.5[ab]	1.4[b]	0.61
Acrid	<.0001	0.0[c]	0.5[a]	0.3[b]	0.1[bc]	0.46
Musty/earthy	0.02	0.1[c]	0.3[a]	0.3[ab]	0.4[a]	0.44
Dark Chocolate	0.14	0.5	0.8	0.7	0.8	0.74
Cocoa	0.84	0.2	0.1	0.2	0.2	0.45
Cardboard	0.40	0.3	0.2	0.3	0.1	0.41
Musty/dusty	0.46	0.1	0.1	0.3	0.1	0.40
Bitter Aftertaste	<.0001	2.4[d]	3.9[a]	3.6[b]	2.8[c]	0.72
Sour Aftertaste	<.0001	1.7[c]	2.7[a]	2.4[a]	2.1[b]	0.60
Astringent Aftertaste	<.0001	1.4[b]	2.3[a]	2.1[a]	1.7[b]	0.56

[abcd] Mean values within a column and effect followed by the same letter are not significantly different($P > 0.05$).
[e] Cold = cold brew, Drip = drip brew, Pour = pour over, French = French press
[f] P value from Analysis of Variance table
[g] RMSE= Root Mean Square Error

Principal Components Analysis

To extract differences between all 16 coffee samples across descriptive sensory attributes, the various datasets were analyzed by principal component analysis (PCA).

For aroma (Figure 4.1), Factors 1 and 2 explained 45.16% of the variability, with Factor 1 (F1) explaining 30.66% and Factor 2 (F2) explaining 14.50%. Across the 16 coffee samples, cold brewed Folgers® 100% Colombia (Colombia Cold Brew) coffee samples differed from all the other coffee samples. The cold brewed coffee samples are all located on the negative side of F1. This showed that the cold brew method had a higher impact on coffee aroma than different roast levels. French press brewed Folgers® 100% Colombia (Colombia French Press), French press brewed Folgers® Black silk (Black Silk French Press), drip brewed Folgers® 100% Colombia (Colombia Drip), and drip brewed Folgers® Black silk (Black Silk Drip) coffee samples clustered together and were highly correlated with aromas responsible for strong coffee. These aromas included woody, burnt, sour, ashy, roasted, smoky, and musty/earthy. Aromas including cocoa, cardboard, musty dusty were generated when evaluating French press brewed Folgers® Classic roast (Classic Roast French press), pour over brewed Folgers® Breakfast blend (Breakfast Blend Pour Over), and pour over brewed Folgers® 100% Colombia (Colombia Pour Over) coffee samples. Cold brewed Folgers® Breakfast blend (Breakfast Blend Cold Brew) coffee samples generated sweet, caramelized, and berry fruit aromas. Cold brewed Folgers® Classic roast (Classic Roast Cold Brew) and pour over brewed Folgers® Black silk (Black Silk Pour Over) generated dark fruity, grain and dark chocolate aromas.

For flavor, texture, and aftertaste attributes (Figure 4.2), Factors 1 and 2 explained 54.5% of the variability with Factor 1 explaining 43.95% and Factor 2 explaining 10.55% of the variation. All the cold brewed coffee samples were located on the negative side of F1 which are opposite of flavor attributes representative of strong coffee. This indicated that even if a darker roasted coffee was used, cold brewing will likely result in a light/mild flavor. Overall sweet, sweet, grain, fruity berry, fruity non-citrus, and cocoa flavors were related to Classic Roast Cold Brew, Colombia Cold Brew and Colombia Pour Over coffee samples. Pour over brewed Folgers® Classic roast (Classic Roast Pour Over), French press brewed Folgers® Breakfast blend (Breakfast Blend French Press) and Breakfast Blend Pour Over coffee produced cardboard and woody flavor; and were highly blended. Colombia Drip and Colombia French press showed quite a difference from the other coffee samples. Flavor attributes responsible for strong coffee, including bitter, burnt, and sour, correlated with Colombia French press and Colombia Drip. All three aftertaste attributes and mouth drying/astringent also correlated with Colombia French press and Colombia Dip. Flavors attributes including ashy, roasted, musty/earthy, dark chocolate, and nutty as well as textures including thickness and body fullness clustered with all four types of coffee brewed by the drip method, and Classic Roast French Press and Black Silk French Press coffee samples.

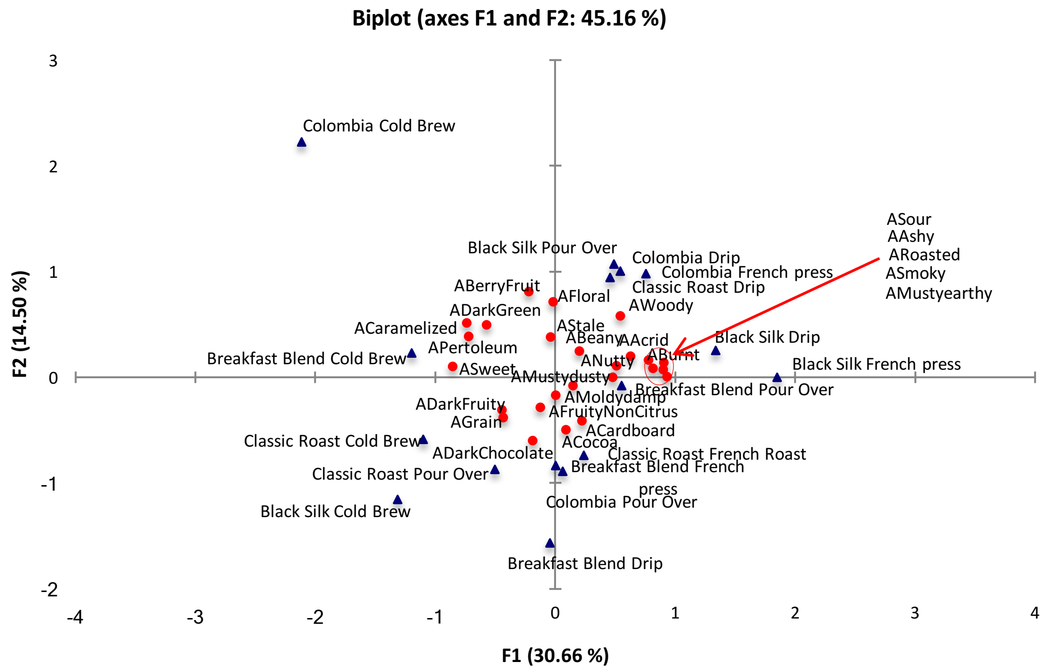

Figure 4.1 Principal Components Analysis Biplot of descriptive sensory aroma attributes. Sensory attributes (●) and coffee samples (▲)

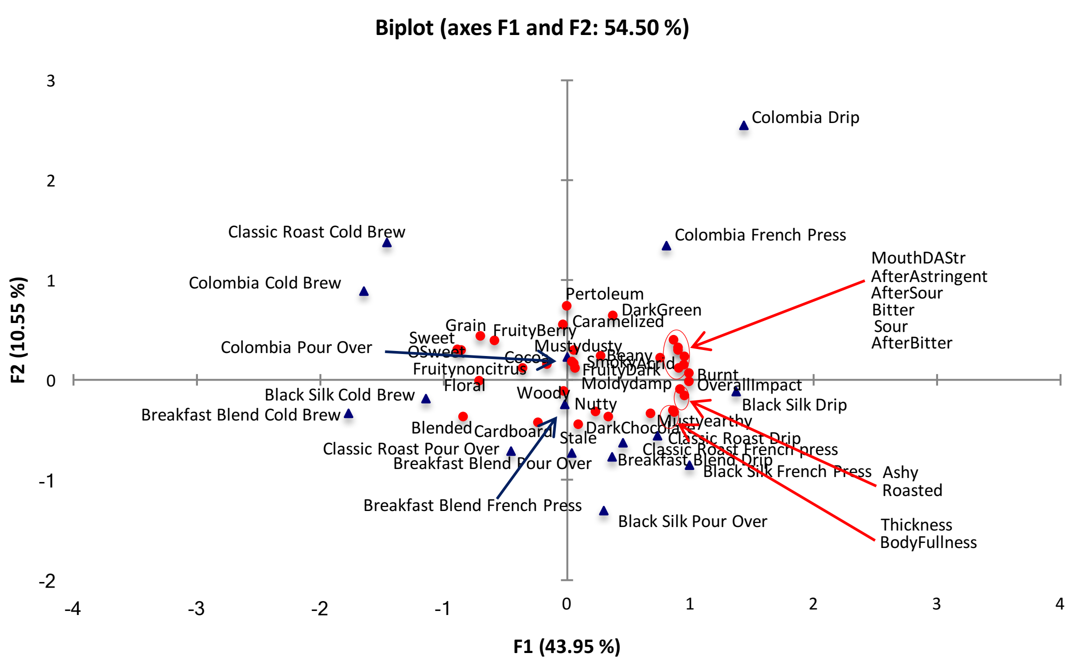

Figure 4.2 Principal Components Analysis Biplot of descriptive sensory flavor, texture and aftertaste attributes. Sensory attributes (●) and coffee samples (▲)

Chemical Analysis

Least square means of chemical analysis components, including yield (%), pH (50°C and 20°C), Brix (%) and TDS (%), were affected by coffee types and brew methods (Table 4.5). All chemical components except yield (%) differed ($P < 0.05$) across coffee types. All chemical components tested, five in total, differed ($P < .0001$) across brew methods.

Yield (%) means the proportion of brewed coffee to the amount of water initially incorporated for extraction. In this research, yield differed across brew methods ($P < .0001$) but not coffee types ($P > 0.05$). Among the four brew methods, French press brewed coffee showed the lowest yield at 89.4% ($P < .0001$), while cold brewed coffee had the highest at 91.8% ($P < .0001$).

The pH values were measured at both 50°C and 20°C. It was found that pH value increased between 50°C and 20°C across different coffee types and brew methods. Across the four coffee types, Folgers® 100% Colombia coffee showed the lowest pH values ($P < .0001$) at both 50°C and 20°C, while Folgers® Black silk coffee showed the highest ($P < .0001$) pH respectively. Fuse et al. (1997) found that there was a correlation between pH values and coffee roast degree. However, this correlation was not replicated in this study as Folgers® 100% Colombia coffee, the medium-dark roast coffee, showed the lowest pH (20°C and 50°C). This could be attributed to the different coffees used in the two studies. Among all four brew methods, cold brewed coffee showed the highest pH ($P < .0001$) at both 50°C and 20°C, measuring 5.30 and 5.47, respectively, while French press had the lowest pH ($P < .0001$). In a study did by Gloess et al. (2013), Espresso-Nespresso brew method produced the lowest pH coffee (pH = 5.51, measured at 20°C), and pH increased from drip coffee to French press (pH = 5.92, measured at 20°C). These results differed from what was found in this study as French press recorded a lower pH (pH = 5.26) at 20°C than drip coffee (pH = 5.29). This could be attributed to the different coffee brewers used to make the drip and French press coffee in the two studies.

Total dissolved solids (%, TDS) and Brix (%), both the extraction level, were also tested in this study. Between the four coffee types, Folgers® 100% Colombia coffee showed the highest brix% ($P < 0.05$) while Folgers® Classic roast was the lowest. For TDS, light roasted coffee (Folgers® Breakfast blend and Folgers® Classic roast) was lower than dark roasted coffee (Folgers® 100% Colombia and Folgers® Black silk). Gloess et al. (2013) declared that TDS correlated almost linearly with Brix as they are both methods to test the extraction level of coffee. The higher the temperatures and pressures, the higher the extraction of water-soluble components in the coffee (Trugo et al., 1984; Lopez-Galiea et al., 2007; Gloss et al., 2013). This could explain the reason why in this study cold brewed coffee showing the lowest ($P < .0001$) on both TDS and Brix as a result of being brewed at a lower temperature than the other three brew methods and under lower pressure as compared to French press.

Table 4.5 Least square means for yield (%), pH (50°C & 20°C), Brix (%) and TDS (%) for four commercial coffee blends and four brew methods.

Treatment	Yield (%)	pH50C	pH20C	Brix(%)	TDS(%)
Coffee[d]					
P value[f]	0.18	<.0001	<.0001	0.01	<.0001
Breakfast[d]	90.8	5.21[b]	5.39[b]	1.4[bc]	1.0[b]
Classic[d]	91.0	5.19[b]	5.36[b]	1.4[c]	1.0[b]
Colombia[d]	90.7	4.94[c]	5.12[c]	1.5[a]	1.1[a]
Black[d]	90.3	5.27[a]	5.46[a]	1.4[ab]	1.1[a]
Brew Method[e]					
P value[f]	<.0001	<.0001	<.0001	<.0001	<.0001
Cold[e]	91.8[a]	5.30[a]	5.47[a]	1.2[c]	0.9[c]
Drip[e]	90.7[b]	5.13[b]	5.29[bc]	1.5[a]	1.2[a]
French[e]	89.4[c]	5.10[b]	5.26[c]	1.5[a]	1.2[a]
Pour[e]	91.0[b]	5.10[b]	5.31[b]	1.3[b]	1.0[b]
RMSE[g]	1.38	0.11	0.08	0.14	0.08

[abc]Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[d] Breakfast = Folgers® Breakfast blend, Classic = Folgers® Classic roast, Colombia = Folgers® 100% Colombia, Black= Folgers® Black silk
[e] Cold = cold brew, Drip = drip brew, Pour = pour over, French = French press
[f] P value from Analysis of Variance table
[g] RMSE= Root Mean Square Error

Correlation Between Chemical and Descriptive Sensory Analysis

Partial least squares regression was conducted to determine the correlation between chemical attributes and sensory attributes (Figure 4.3 and Figure 4.4). As expected, pH20°C (pH20C) and pH 50°C (pH50C) were clustered as well as Brix% (BrixP) and TDS% (TDSPer).

The BrixP and TDSPer were closely clustered with strong coffee aroma attributes including roasted, burnt, ashy, sour and acrid aroma attributes. These findings were consistent with those of Gloess et al. (2013) who reported total solid concentration influenced the intensity of aroma and sensory attributes including body, roast, bitter, bitter aftertaste and astringent aftertaste. Clarke et al. (2001) also found that the total solid concentration was mainly responsible for the coffee acidity. Those findings were both found in this study.

Petracco (2001) and Rao (2010) found that from a sensory standpoint, low extraction yields resulted in sour and sweet flavors, while high extraction yields exhibited bitter and astringent flavor that disagreed with the findings of this study. In this study, high yield percentage coffee samples exhibited sweet and fruity aromas as well as flavors. The reason for this difference may be due to the new cold brew method tested in this study which made mild but high yield coffee.

The correlation between pH and sensory perceived acidity has been widely studied. In this study, there was no correlation found between pH and sour attributes (aroma, flavor, and aftertaste), similar to a study by Andueza et al. (2007). However, in contrast, Maier et al. (1982, 1984a, 1984b, 1987), performed an extensive study on the acids in coffee. These studies ranged from the composition of the acids in coffee to the correlation of the analytically measured acidity with the sensory attribute acidity. The sensory evaluation was performed on cold coffee extracts (40°C), diluted with water, and showed a linear correlation between the titratable acidity and the acidic taste of different coffee extractions, but no correlation with the pH value of the brews. In their studies, they identified 67% of the acids contributing to the titratable acidity as well as the sensory acidity of the coffee extract, with acetic and citric acid being the most important ones (Gloess et al., 2013).

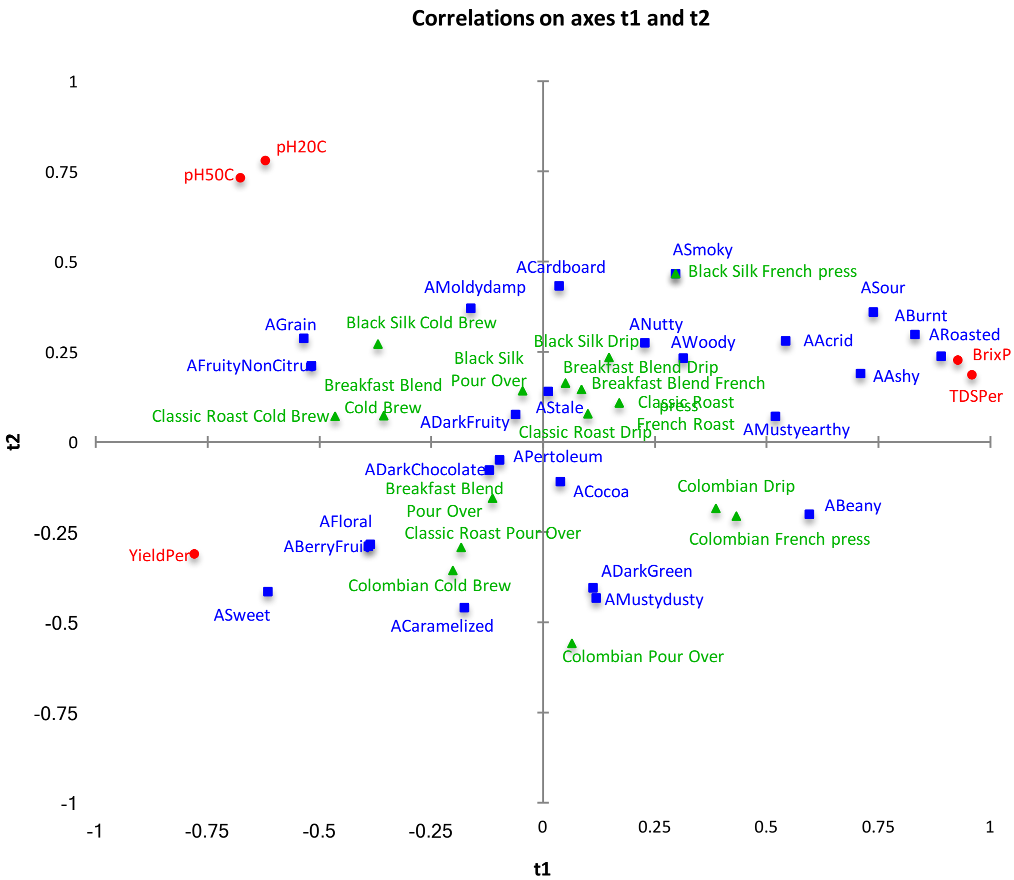

Figure 4.3 Partial least squares regression biplot for descriptive sensory aroma attributes (■), chemical test (●) and coffee samples (▲)

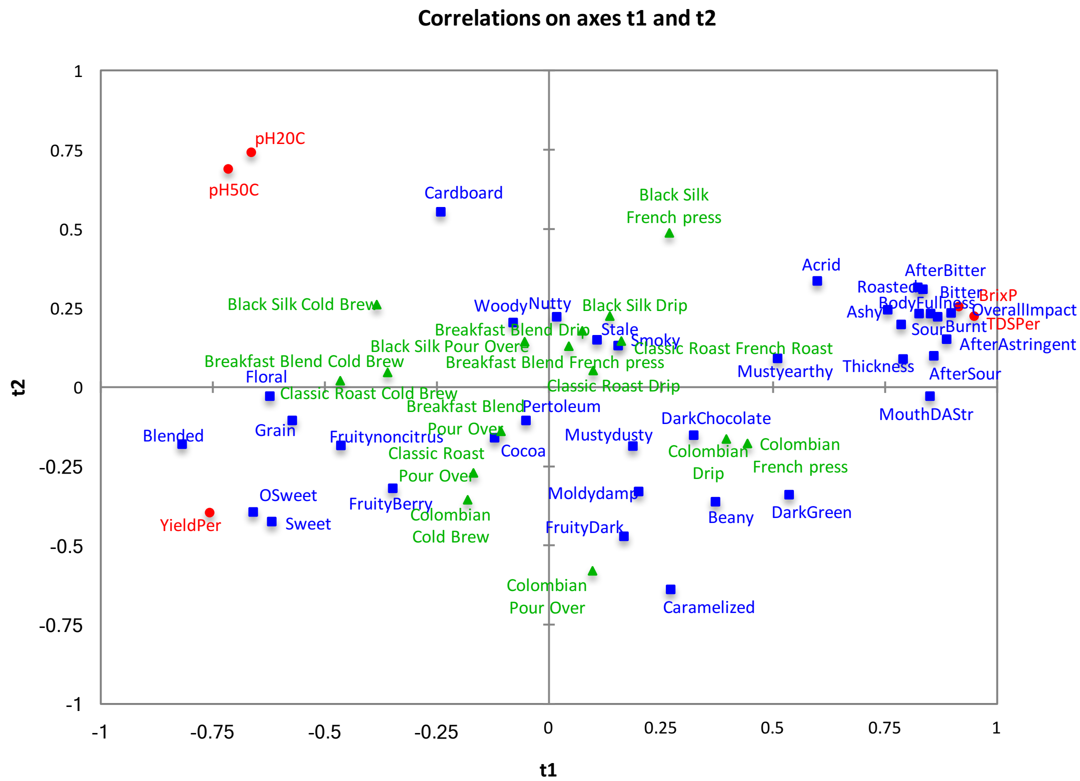

Figure 4.4 Partial least squares regression biplot for descriptive attributes (flavor, texture, and aftertaste) (■), chemical test (●) and coffee samples (▲)

GC/MS Data Analysis

Volatile aromatic chemical compounds (n = 271) were identified in the coffee samples (Table 4.6). The total ion count mean under the curve for each compound was reported.

Coffee Types and Brew Methods Interactions

Among the 271 volatile compounds found on coffee samples in this study, thirteen volatile compounds showed significant differences ($P < 0.05$) when testing the interaction of coffee types and brew methods (Table 4.7). Table 4.8 showed the classification of those volatile compounds. Folgers® Black silk coffee prepared using cold brew showed the highest ($P < 0.05$) amount of 1-ethyl-1H-pyrrole (C6) while all the other coffee samples showed none. French press brewed Folgers® Black silk coffee produced the highest ($P < 0.01$) amount of dicyclobutylidene oxide (C28), 2-pentyl furan (C133), 2,7-dimethyl oxepine (C136) and 3-thiophenecarboxaldehyde (C206). 2-pentyl furan (C133) was not detected in all four cold brew coffee and was lower on pour over coffee than coffee with higher roast levels (Folgers® 100% Colombia and Folgers® Black silk). Pour over brewed Folgers® Black silk coffee produced the highest ($P < 0.05$) amount of 3-methyl-2-pyridinamine (C222) and was the only coffee that did not detect any 2,7-dimethyl oxepine (C136).

Differences Among Coffee Types

Least square means of 44 gas chromatography (GC) volatile compounds were affected by coffee blends (Table 4.9). Farah (2012) indicated that some compounds affected by roasting conditions including 5-methyl-furancarbaldehyde, 2-methoxyphenol, 2-methyl pyridinepyrazin, furfural, furfurylformate, 2-furanomethanolacetate, 1-(2-furanylmethyl)-1H-pyrrol, 1-(1H-pyrrol-2-yl)-ethanone, and 4-ethyl-2-metoxyphenol. Toci (2010) found various impact compounds, including 3-pentanedione, 2,5-dimethylpyrazine, 2-ethylpyrazine, 2,3-dimethylpyrazine, 3-ethyl-2,5-dimethylpyrazine, 2-methylbutanal, 2-ethylguaiacol, and 4-vinylguaiacol were correlated to different degrees of roast.

2,2'-methylenebis-furan (C38), bicyclo[3.3.1]nonane (C129), 2,3-hexanedione (C76), 4-(2-furanyl)-3-buten-2-one (C183), 3-methoxy-5-methyl-2-cyclopenten-1-one (C204) increased ($P < 0.05$) when roasting level increased while ethyl-pyrazine (C106) and 2,5-dimethyl-pyrazine (C140) decreased ($P < 0.05$) when roasting level increased. Somporn et al. (2011) stated that most of the volatile compounds became less important as the degree of roast was increased (from light to medium roast). This was most likely due to losses as the roast temperature increased, or after exposure to high temperatures for long periods. There were increases in the contributions of the less volatile compound such as furans, pyrazine, and pyridine (Somporn et al., 2011). However, Altaki (2011) found that low roasting level decreased the final furan content, whereas high roasting level resulted in high concentrations. In this study, light roast coffee (Folgers® Breakfast blend and Folgers® Classic roast) produced lower amount of furans and pyridines but higher pyrazines than dark roast coffee (Folgers® 100% Colombia and Folgers® Black silk).

Morais et al. (2007) indicated that a medium roast resulted in greater differences in odorific activities for low-quality seeds (2-methylpropanal, 3-methylbutanal, 2-methylbutanal and 2-methylthio-methylfuran) that matched what was found on this study. As Folgers® 100% Colombia had 18 volatile compounds out of the 44 showed highest ($P < 0.05$) than the other three coffee types, which was the most across four coffee types.

Differences Among Brew Methods

Least square means of GC volatile compounds were affected by coffee blends (Table 4.10). Thirty-seven volatile compounds out of 271 differed ($P < 0.05$) across brew methods. Cold brewed coffee was low on most of those volatile compounds especially α-ethylidene-benzeneacetaldehyde (C86), ethylidene (C110), and 2,2'-methylenebis furan (C38), 2-[(methyldithio)methyl] furan (C95), 2-pentyl furan (C133) but highest ($P < 0.05$) on 1,3-pentadiene (C61), 5-methyl-2-pyridinamine (C72), nona-3,5-dien-2-one (C224), 4-phenylbut-3-ynylamine (C226), 5-methyl-3-heptanone (C121). Drip brewed coffee produced the highest ($P < 0.05$) amount of 2-(carboxymethylthio)-pyrimidine (C177), 1-(2-thienyl) ethanone (C94), 2-butenal (C247), and 1-(5-methylfurfuryl)-pyrrole (C109) and pour over brewed coffee produced the highest ($P < 0.05$) amount on 1-ethyl-1H-pyrrole-2-carboxaldehyde (C111), and 3-methoxy-5-methyl-2-cyclopenten-1-one (C204) but lowest ($P < 0.05$) on 1-(2-thienyl) ethanone

(C94). Coffee brewed using the French press method produced the highest ($P < 0.05$) amount on 1-(2-furanylmethyl)-1H-pyrrole (C5), dimethyl trisulfide (C107), 2,7-dimethyl oxepine (C136), 2-ethenyl-5-methyl pyrazine (C163), 1-methyl-1H-indole (C174) , and some furans (C8, C38, C118,C133, C184).

Caporaso et al. (2014) reported that 2-furanmethanol acetate, 2,5-dimethylfuran and furfuryl methyl ether were the main volatile compounds that differed across brew methods (espresso, mocha and American brew which was the same as drip used in this study). They found furans were the most abundant volatile compounds in all the coffee brews, followed by total phenolic compounds, pyrazines, aldehydes, and ketones. Espresso coffee showed a higher content on furans with respect to American brews. These results were the same as Altaki (2011) who found that furan concentrations in regular brews prepared with an espresso machine were higher than those obtained with a home drip coffee maker. López-Galilea et al. (2006) reported that ketones found on drip coffee brew methods were more abundant than an espresso one. On this study, ketones found on French press methods were most abundant than the other three brew methods.

Table 4.6 Overall means and standard deviation values for volatile, aromatic chemicals (n = 271) identified by the AromaTrax System.

Code	Volatile Compounds	Mean Total Ion Count	Standard Devation
C1	1-(1-Propynyl)cyclopropanol	3742.0	10166.1
C2	1H-Pyrrole	147127.6	103609.7
C3	1H-Pyrrole-2-carboxaldehyde	18848.0	17962.6
C4	1-Methyl-1H-pyrrole-2-carboxaldehyde	236816.2	169507.1
C5	1-(2-Furanylmethyl)-1H-pyrrole	476090.8	213559.0
C6	1-Ethyl-1H-pyrrole	12559.6	65877.3
C7	1-Methyl-1H-pyrrole	477152.7	416842.3
C8	2-(2-Propenyl)-furan	158644.9	80779.8
C9	2-Methyl-2-butenal	38638.6	32232.1
C10	2-Furancarboxaldehyde	2575463.5	1192669.4
C11	2-Furanmethanol	1201122.5	749730.3
C12	2-Furanmethanol acetate	1733518.2	1172743.5
C13	2-Methoxy-4-vinylphenol	256237.8	187889.7
C14	2-Methyl-3-β.-furul propenal	5209.9	8077.0
C15	2-Pyridinemethanamine	26414.8	97677.7
C16	2-Vinylfuran	1273.3	6304.3
C17	2,3-Pentanedione	149857.4	123938.2
C18	5-Furandione-dihydro-3-methyl-2	794.2	2601.8
C19	2,2-Dimethyl-3-hexanone	2786.7	7831.4
C20	2,4-Dimethyl-3-pentanone,	10946.3	20471.8
C21	5-Methyl furfural	1055107.2	1046818.8
C22	Methyl ester acetic acid	10360.9	12838.7
C23	2-Methoxy-benzenamine	11414.2	20115.8
C24	2-Methoxy-benzeneethanol	143723.8	100854.8
C25	2-Hydroxy-methyl ester benzoic acid	74635.5	53316.1
C26	2-Methyl-utanal	163217.2	192348.0
C27	3-Methyl-butanal	68491.4	86516.5
C28	Dicyclobutylidene oxide	19987.1	27170.8
C29	Dimethyl trisulfide	50976.9	87572.2
C30	Dimethyl disulfide	83756.8	97531.8
C31	1-(1-Methyl-1H-pyrrol-2-yl)-ethanone	85237.7	113832.2
C32	1-(2-Furanyl)-ethanone,	447550.3	286084.1
C33	2-(2-Furanylmethyl)-5-methyl-furan	155014.9	83222.8

Table 4.6 Continued

Code	Volatile Compounds	Mean Total Ion Count	Standard Devation
C34	2-(Methoxymethyl)-furan	108184.0	58622.1
C35	2-[(Methylthio)methyl]-furan,	347829.3	240725.0
C36	2-Methyl-Furan,	316660.2	357134.6
C37	2,2'-[Oxybis(methylene)]bis-furan	105920.8	53746.1
C38	2,2'-Methylenebis-furan	547658.1	304985.9
C39	2,5-Dimethyl-furan	99930.0	98151.9
C40	3-Methyl-furan	21589.3	96236.9
C41	3-Phenyl-furan	37270.7	28348.1
C42	iso Butyraldehyde	6649.3	11223.1
C43	N-Methyl-2,5-dimethylpyrrole	2754.0	4346.3
C44	2-Amino-phenol	733.3	3430.7
C45	2-Methoxy-phenol	212730.4	137639.8
C46	2-Methoxy-4-(2-propenyl)-phenol	1124.5	2912.6
C47	4-Methyl-phenol	4481.9	12470.7
C48	2-Ethyl-6-methyl-pyrazine	180091.4	252571.4
C49	3-Ethyl-2,5-dimethyl-pyrazine	122209.5	82694.3
C50	Methyl-pyrazine	679732.3	610697.4
C51	Pyridine	1060872.5	638407.4
C52	4,6-Dimethyl-pyrimidine	103806.4	245743.4
C53	Styrene	11813.2	14679.7
C54	Thiophene	5058.7	18919.1
C55	2-Methyl-thiophene	19955.3	21430.6
C56	Vinylfuran	242843.6	185311.1
C57	(1H-Pyrrol-3-yl)acetic acid	9832.4	18950.3
C58	1-Formylcyclopentene	9282.8	15771.2
C59	1,2-Pentadiene	993.8	3578.7
C60	1,3-Diazine	60839.8	77393.4
C61	1,3-Pentadiene	1206.8	3048.0
C62	1H-Indole	17772.0	19629.2
C63	3-Ethyl-2-hydroxy-2-cyclopenten-1-one	11825.5	33047.0
C64	2-Formyl-1-methylpyrrole	57223.3	98596.6
C65	2-Furancarbonitrile	1820.6	4430.6
C66	5-Methyl-2-furancarboxaldehyde	1560827.5	944694.1
C67	2-Furanmethanol propanoate	60855.3	44248.4

Table 4.6 Continued

Code	Volatile Compounds	Mean Total Ion Count	Standard Devation
C68	2-Heptanol	8877.0	18513.4
C69	2-methyl pyrazine	615220.8	621515.4
C70	2-Pentanone	13563.7	42003.3
C71	1-(Acetyloxy)-2-propanone	104877.3	104040.2
C72	5-Methyl-2-pyridinamine	69130.7	152052.0
C73	2-Thiophenecarboxaldehyde	93208.4	47636.4
C74	2,3-Butanedione	27931.5	32167.3
C75	2,3-Dihydro-6-methylthieno[2,3c]furan	213198.1	157232.6
C76	2,3-Hexanedione	17667.3	36977.7
C77	Dihydro-3-methylene-2,5-furandione	731.0	2290.8
C78	2H-Pyran-2-one	2510.5	5637.9
C79	4-Octanone	9451.4	12862.1
C80	5-Methyl--6,7-dihydro-(5H)-N-acetyl-4(H)-pyridine	22771.3	26557.9
C81	Cyclopentapyrazine	10673.3	19190.7
C82	Acetylpyrrole	3941.7	8244.2
C83	Benzaldehyde	125145.1	108252.4
C84	4-Methoxy-benzenamine	64760.6	113629.6
C85	Methyl-benzene	18048.0	33544.6
C86	α-Ethylidene-benzeneacetaldehyde	11818.9	10107.0
C87	4-Methyl-benzenemethanol	3454.1	21783.8
C88	Butanal	4064.2	9092.6
C89	2-(Ethenyloxy)-2-methyl-butane	16558.9	24984.0
C90	cis-2-Methyl-5-n-propenylfuran	9694.4	50602.4
C91	1,4,5,6-Tetrahydro-cyclopentapyrazole	29428.4	44324.0
C92	1-(1H-Pyrrol-2-yl)-ethanone	44077.1	17499.2
C93	1-(2-Methyl-1-cyclopenten-1-yl)-ethanone	9349.6	22000.6
C94	1-(2-Thienyl)-ethanone	21514.0	18048.7
C95	2-[(Methyldithio)methyl]-furan	47385.0	40896.8
C96	2-Ethyl-furan	6240.9	8571.3
C97	Hexanal	41458.5	57108.1
C98	Nonanal	91413.6	124084.7
C99	Phenol	100874.7	50378.5
C100	2-Methyl-phenol	39454.2	107466.4
C101	3-Ethyl-phenol,	2669.4	4281.0

Table 4.6 Continued

Code	Volatile Compounds	Mean Total Ion Count	Standard Devation
C102	4-Amino-phenol	907.1	3178.9
C103	4-Ethyl-2-methoxy-phenol	55092.8	68609.9
C104	2-Methyl-propanal	7058.0	13316.7
C105	2-Ethyl-3,5-dimethyl-pyrazine	25116.3	59473.7
C106	Ethyl-pyrazine,	286799.3	215452.5
C107	Dimethyl trisulfide	95956.7	93255.8
C108	1-(2-Furyl)-2-propanone	26884.9	28385.1
C109	1-(5-Methylfurfuryl)-pyrrole	12403.0	16392.5
C110	1-Furfuryl-2-formyl pyrrole	10081.2	14158.9
C111	1-Ethyl-1H-pyrrole-2-carboxaldehyde	13371.9	22453.9
C112	2,5-Dimethyl-1H-pyrrole	19885.8	20447.3
C113	3-Ethyl-2,4-dimethyl-1H-pyrrole	6910.5	18661.9
C114	2-Acetyl-5-methylfuran	3038.0	6655.0
C115	2-Methyl-3(2-furyl)acrolein	10506.6	10507.2
C116	4-Methyl-2-pentanone	3374.9	13527.8
C117	N-Methyl-2-pyridinamine	107.7	441.6
C118	2-Vinyl-5-methylfuran	316403.6	321687.4
C119	2,2'-Bifuran	51287.3	44127.9
C120	3-Ethyl-2-formylthiophene	144802.1	151723.4
C121	5-Methyl-3-heptanone	4563.1	14065.6
C122	3-Penten-2-one	5792.5	15202.3
C123	4-N-pyrrolyl-1,2-epoxybutane	10815.0	19977.2
C124	Acetic acid ethenyl ester	3823.7	10730.7
C125	3-Maethoxy-benzenamine	687.5	4763.0
C126	4-Ethenyl-1,2-dimethoxy-benzene	7253.1	9342.7
C127	Benzofuran	39679.1	43598.8
C128	Bi-(2-furyl)-methane	260871.1	376886.9
C129	Bicyclo[3.3.1]nonane	7345.9	22642.7
C130	3-Methyl-2-furanylmethyl ester-butanoic acid	2453.7	7959.7
C131	Camphor	4197.8	13048.8
C132	3-MAethyl-cinnoline	4695.9	13566.0
C133	2-Pentyl furan	18366.0	28784.9
C134	Furfuryl formate	38515.5	31547.3
C135	N Heptanal eptanal	653.9	3324.3

Table 4.6 Continued

Code	Volatile Compounds	Mean Total Ion Count	Standard Devation
C136	2,7-Dimethyl-oxepine	53349.8	61767.9
C137	3-Methyl-phenol	110967.5	218410.7
C138	2-Ethyl-5-methyl-pyrazine	36663.2	53472.9
C139	2,3-Dimethyl-pyrazine	11830.5	29078.1
C140	2,5-Dimethyl-pyrazine	165800.0	107645.6
C141	2,6-Dimethyl-pyrazin	144253.1	270206.2
C142	Ethenyl-pyrazine	25348.6	38719.8
C143	Pyrazinecarboxamide	4934.8	17559.0
C144	4-Methyl-pyridine	2575.3	8199.6
C145	Pyrimidine	44709.8	77836.0
C146	3-Methyl-thiophene	14879.5	20391.2
C147	trans-Furfurylideneacetone	1177.4	2910.6
C148	2,3-Dihydro-1-methyl-1H-indole-5-carboxaldehyde	1880.3	4454.7
C149	2-Butylfuran	4177.2	10867.5
C150	2,3-Dimethyl-3-isopropyl-cyclopentene	6118.0	12687.0
C151	2H-1-benzopyran	4400.6	12899.1
C152	3,4,4-Trimethyl-2-pentenal	5359.7	17175.5
C153	4-Methylenecyclohexanone	4590.8	19252.9
C154	4-Pyridinemethanol	81708.3	159171.5
C155	Acetic acid	18262.9	59072.8
C156	Benzenemethanol	1025.8	4229.0
C157	2-Furanylmethyl ester butanoic acid	5306.1	16653.7
C158	1-(1,4-Dimethyl-3-cyclohexen-1-yl)-ethanone	1345.0	4038.7
C159	(E)-2,2'-(1,2-Ethenediyl)bis-furan	731.9	1970.8
C160	Methyl salicylate	25241.7	43469.9
C161	2-Ethyl-phenol	3148.4	18854.3
C162	3,4-Dimethyl-phenol	235.0	1392.6
C163	2-Ethenyl-5-methyl-pyrazine	2536.3	6895.1
C164	Pyrrole	25531.7	59388.8
C165	trans-2-Methyl-5-n-propenylfuran	10736.0	36872.2
C166	1-(5-Methyl-2-furanyl)-1-propen-3-al	2229.7	6456.9
C167	1-(5-Methyl-2-furyl)-2-propanone	5882.2	14641.3
C168	1-(5(Methyl-2-furanyl)-1-buten-3-one	1374.1	4971.9
C169	1-Ethyl-2-formyl pyrrole	8357.8	21924.8

Table 4.6 Continued

Code	Volatile Compounds	Mean Total Ion Count	Standard Devation
C170	1-(2-Furanyl)-1-propanone	36522.6	50840.1
C171	1-(5-Methyl-2-furanyl)-1-propanone	1169.6	4228.7
C172	Diacetate 1,2-ethanediol	19058.1	45995.9
C173	2-Methyl-1,3-butadiene	3286.7	6952.8
C174	1-MAethyl-1H-indole	3789.3	9091.2
C175	2,3-Dimethyl-1H-pyrrole	3280.6	14876.4
C176	2,4-Dimethyl-1H-pyrrole	4272.5	18346.3
C177	2-(Carboxymethylthio)-pyrimidine	1122.2	4393.6
C178	2-Acetyl-3-ethylthiophene	7106.6	17280.9
C179	4-(5-Methyl-2-furanyl)-2-butanone	2423.1	11678.8
C180	2,4-Dimethylpyrrole	13572.1	28577.1
C181	3-Methyl-2(5H)-furanone	298.5	1339.0
C182	3-Amino-4-pyrazolecarbonitrile	34336.2	44562.5
C183	4-(2-Furanyl)-3-buten-2-one	2113.5	3902.4
C184	2-Ethenyl-benzofuran	10460.9	19872.8
C185	2-Methyl-benzofuran	29322.5	37793.4
C186	1-(1-Cyclohexen-1-yl)-ethanone,	8104.1	19928.1
C187	1-(3-Thienyl)-ethanone,	12388.8	17305.0
C188	Furan	7707.7	8928.5
C189	Furfurylmethyldisulfide	6085.8	15293.2
C190	Methanethiol	302.4	924.5
C191	Nicotinyl Alcohol	24086.0	85486.5
C192	3-Amino-phenol	469.9	1883.4
C193	2-(n-Propyl)-pyrazine	1627.1	9172.8
C194	2-Methyl-pyridine	2907.4	10403.4
C195	Toluene	20613.8	51873.8
C196	1-(2-Furyl)-butan-3-one	8345.4	40464.7
C197	2-Ethyl-5-methylthiophene	5570.0	16548.4
C198	3,4-Dimethoxy styrene	3118.8	5604.8
C199	3-Methyl-4-heptanone	5173.8	14104.7
C200	1,4-Dimethyl-bicyclo[2.1.0]pentane	16855.9	37365.1
C201	2-(2-Propenyl)-furan	19855.5	78808.1
C202	4-Ethyl-phenol	596.9	3536.5
C203	Pyrazinamide	6180.2	15507.5

Table 4.6 Continued

Code	Volatile Compounds	Mean Total Ion Count	Standard Devation
C204	3-Methoxy-5-methyl-2-cyclopenten-1-one	2577.7	7075.4
C205	3-Methyl-2,5-furandione	870.4	2773.6
C206	3-Thiophenecarboxaldehyde	7153.4	27418.4
C207	6,7-dihydro-5-methyl-cyclopentapyrazine	1378.1	4082.5
C208	4-Methyl-benzaldehyde	596.4	2605.0
C209	2-Methyl-1H-indole	654.6	2401.4
C210	2-Butanone	3115.4	15172.9
C211	3-Methyl-2-buten-1-ol acetate	1068.5	3891.8
C212	2-Propanone	3037.2	9551.9
C213	2,5-Diethylfuran	1781.7	7371.0
C214	Dihydro-2(3H)-furanone	1206.7	4894.0
C215	4-Heptanone	3487.6	14568.5
C216	Furfurylmethylether	792.0	2505.5
C217	1,3,5-Cycloheptatriene	12224.4	30160.9
C218	5-Methyl-2(1H)-pyridinone	622.2	2550.2
C219	3-Methylbenzyl alcohol	26429.8	64060.7
C220	cis-iso Eugeno	1887.1	3576.9
C221	Pyrazine	32448.6	67372.9
C222	3-Methyl-2-pyridinamine	26747.8	105652.6
C223	1,2-Diethylidene-cyclobutane	1061.2	3566.9
C224	Nona-3,5-dien-2-one	1804.4	5694.4
C225	Pentanal	11209.6	34538.7
C226	4-Phenylbut-3-ynylamine	2155.2	5574.8
C227	methyl ester, 2-methyl-benzoic acid	1240.6	5341.3
C228	1,2,3,3-Tetramethyl-cyclopenten-4-one	45.8	317.5
C229	(E)-2-Methoxy-4-(1-propenyl)-phenol	305.9	1205.1
C230	2-Hexadecanol	3653.3	11790.0
C231	2-Pyrimidinamine	1442.6	8160.1
C232	3-Hexanone	2481.1	10542.7
C233	Heptanal	2817.9	9201.3
C234	1,4-Pentadiene	1689.0	4441.2
C235	3-Pyridinol	5861.3	15731.1
C236	3-Methyl-benzaldehyd	2350.1	15446.1
C237	Decanal	1453.7	7055.4

Table 4.6 Continued

Code	Volatile Compounds	Mean Total Ion Count	Standard Devation
C238	2-Ethenyl-6-methyl-pyrazine	1524.7	4959.2
C239	2,4-Hexadienal	3300.9	12766.6
C240	1-Methoxy-3-methyl-benzene	2037.9	9186.2
C241	Furfuryl pentanoate	307.8	1369.7
C242	2-(1-Methylethyl)-thiophene	826.8	4353.6
C243	4-N-Pyrrolylbutane-1,2-diol 1-p-toluenesulfonate	4007.4	11787.6
C244	2-Propenyl ester-2-furancarboxylic acid	2988.8	13223.1
C245	1-Methoxy-4-(methylthio)-benzene	3714.5	14766.7
C246	2,5-Dimethyl-3-propyl-pyrazine	371.3	2343.2
C247	2-Butenal	2260.3	6508.2
C248	2-Formyl-5-methylthiophene	1999.2	10162.3
C249	2,5-Dimethyl-3-ethylfuran	3049.6	7939.3
C250	6-Methyl-2(1H)-pyridinone	140.5	718.8
C251	3,5-octadiene-2-one	11823.4	43097.0
C252	3,6-Dimethyl-2H-pyran-2-one	5036.9	12392.0
C253	2-Methyl-benzaldehyde	821.0	2792.1
C254	2-Hydroxy-ethyl ester-benzoic acid	527.6	2177.9
C255	Tridec-2-ynyl ester-2-furoic acid	1322.6	4566.5
C256	3-Methyl-2(1H)-pyridinone	206.9	1080.7
C257	2-Ethyl-5-methyl-furan	10032.0	30152.4
C258	2-Butanoyl-5-methylfuran	1683.3	6428.7
C259	3-Hydroxy-2-methylene-4-methyl-4-pentenenitrile	5766.3	23433.7
C260	2,3-Dihydro-benzofuran,	92.6	450.5
C261	3-Ethoxy-1-propen	17370.7	57643.0
C262	Furfurylideneacetone	289.9	1206.0
C263	4-(2-Propenyl)-1H-imidazole,	162.5	639.7
C264	3-Ethyl-2,5-dimethyl-1H-pyrrole	605.8	4196.9
C265	1-(2-Hydroxy-5-methylphenyl)-ethanone	1679.2	6039.4
C266	1-(2-Hydroxyphenyl)-ethanone	961.0	3172.2
C267	Octanal	1298.7	6306.4
C268	3,6-iso Benzofuroquione	87.4	343.5
C269	2-Butanoyl furan	1971.7	6844.0
C270	4,6-Dimethylpyridin-2(1H)-one	4703.8	14682.5
C271	2,3-Dimethyl-1,3-heptadiene	4093.9	15011.2

Table 4.7 Least square means for GC volatile compounds of brew methods and coffee types interactions.

Treatment	1-Ethyl-1H-pyrrole (C6)	Dicyclobutylidene oxide (C28)	1,2-Pentadiene (C59)
P value[f]	0.01	0.003	0.03
Breakfast*Cold[g]	0[b]	12178[bc]	0[c]
Breakfast*Drip[g]	0[b]	8131[bc]	0[c]
Breakfast*French[g]	0[b]	0[c]	0[c]
Breakfast*Pour[g]	0[b]	9576[bc]	0[c]
Classic*Cold[g]	0[b]	10910[bc]	0[c]
Classic*Drip[g]	0[b]	31386[bc]	0[c]
Classic*French[g]	0[b]	34862[b]	0[c]
Classic*Pour[g]	0[b]	21002[bc]	8995[a]
Colombia*Cold[g]	0[b]	0[c]	0[c]
Colombia*Drip[g]	0[b]	35620[b]	5326[ab]
Colombia*French[g]	0[b]	0[c]	0[c]
Colombia*Pour[g]	0[b]	26623[bc]	0[c]
Black*Cold[g]	200953[a]	15793[bc]	1580[bc]
Black*Drip[g]	0[b]	0[c]	0[c]
Black*French[g]	0[b]	84592[a]	0[c]
Black*Pour[g]	0[b]	29121[bc]	0[c]

Table 4.7 Continued

Treatment	3-Ethyl-2-hydroxy-2-cyclopenten-1-one (C63)	2,3-Hexanedione (C76)	2-Pentyl furan (C133)
P value[f]	0.04	0.04	0.03
Breakfast*Cold[g]	7048[bc]	0[c]	0[d]
Breakfast*Drip[g]	7048[bc]	0[c]	0[d]
Breakfast*French[g]	0[c]	0[c]	27609[bcd]
Breakfast*Pour[g]	0[c]	0[c]	12786[d]
Classic*Cold[g]	0[c]	0[c]	0[d]
Classic*Drip[g]	0[c]	0[c]	1969[d]
Classic*French[g]	0[c]	0[c]	57805[ab]
Classic*Pour[g]	0[c]	21145[bc]	21772[cd]
Colombia*Cold[g]	0[b]	100194[a]	0[d]
Colombia*Drip[g]	87544[a]	2876[c]	52450[abc]
Colombia*French[g]	10639[bc]	15741[bc]	8364[d]
Colombia*Pour[g]	49213[ab]	45710[bc]	0[d]
Black*Cold[g]	34764[bc]	56671[ab]	9007[d]
Black*Drip[g]	0[c]	40337[bc]	27609[bcd]
Black*French[g]	0[c]	0[c]	72145[a]
Black*Pour[g]	0[c]	0[c]	0[d]

Table 4.7 Continued

Treatment	2,7-Dimethyl-oxepine (C136)	1-(5-Methyl-2-furanyl)-1-propen-3-al (C166)	2-Acetyl-3-ethylthiophene (C178)
P value[f]	0.0004	0.007	0.03
Breakfast*Cold[g]	11364[de]	0[b]	0[c]
Breakfast*Drip[g]	14725[de]	5438[b]	12248[bc]
Breakfast*French[g]	61821[cde]	0[b]	0[c]
Breakfast*Pour[g]	20107[cde]	0[b]	0[c]
Classic*Cold[g]	46614[cde]	0[b]	0[c]
Classic*Drip[g]	68124[cd]	0[b]	0[c]
Classic*French[g]	137951[ab]	0[b]	0[c]
Classic*Pour[g]	59516[cde]	4172[b]	38442[a]
Colombia*Cold[g]	40168[cde]	0[b]	0[c]
Colombia*Drip[g]	64358[cde]	0[b]	15382[abc]
Colombia*French[g]	6948[de]	17685[a]	0[c]
Colombia*Pour[g]	83399[bc]	0[b]	13353[bc]
Black*Cold[g]	20338[cde]	0[b]	0[c]
Black*Drip[g]	17499[cde]	8379[b]	34281[ab]
Black*French[g]	200663[a]	0[b]	0[c]
Black*Pour[g]	0[e]	0[b]	0[c]

Table 4.7 Continued

Treatment	3-Thiophenecarboxaldehyde (C206)	3-Methyl-2-pyridinamine (C222)	Heptan (C233)	3,6-iso Benzofuroquione (C268)
P value[f]	0.004	0.03	0.03	0.01
Breakfast*Cold[g]	0[b]	0[b]	23805[a]	0[b]
Breakfast*Drip[g]	0[b]	0[b]	8200[bc]	0[b]
Breakfast*French[g]	0[b]	0[b]	0[c]	0[b]
Breakfast*Pour[g]	0[b]	0[b]	0[c]	0[b]
Classic*Cold[g]	0[b]	169143[a]	0[c]	0[b]
Classic*Drip[g]	10978[b]	0[b]	0[c]	0[b]
Classic*French[g]	0[b]	0[b]	13082[ab]	412[b]
Classic*Pour[g]	17076[b]	0[b]	0[c]	0[b]
Colombia*Cold[g]	0[b]	0[b]	0[c]	986[a]
Colombia*Drip[g]	0[b]	0[b]	0[c]	0[b]
Colombia*French[g]	0[b]	0[b]	0[c]	0[b]
Colombia*Pour[g]	0[b]	0[b]	0[c]	0[b]
Black*Cold[g]	0[b]	0[b]	0[c]	0[b]
Black*Drip[g]	0[b]	0[b]	0[c]	0[b]
Black*French[g]	86401[a]	0[b]	0[c]	0[b]
Black*Pour[g]	0[b]	258821[a]	0[c]	0[b]

[abcde] Mean values within a column and effect followed by the same letter are not significantly different(P > 0.05).
[f] P value from Analysis of Variance table
[g] Breakfast = Folgers® Breakfast blend, Classic = Folgers® Classic roast, Colombia = Folgers® 100% Colombia, Black = Folgers® Black silk, Cold = cold brew, Drip = drip brew, Pour = pour over, French = French press

Table 4.8 Category of GC volatile compounds on brew methods and coffee types interactions.

Chemical Category	Volatile Compouds	Sensory Notes	Code
Aldehydes	Heptanal	harsh, fatty[1]	C233
Alkenes	1,2-Pentadiene		C59
	1-(5-Methyl-2-furanyl)-1-propen-3-al	sweet, spicy[1]	C166
	3-Ethyl-2-hydroxy-2-cyclopenten-1-one	caramel[1]	C63
	Dicyclobutylidene oxide		C28
Furans	2-Pentyl furan	fruity, green[1]	C133
Ketones	2-3-Hexanedione	sweet, buttery[1,2]	C76
Quiones	3,6-iso Benzofuroquione		C268
Oxepines	2,7-Dimethyl oxepine		C136
Pyridinamines	3-Methyl-2-pyridinamine		C222
Pyrroles	1-Ethyl-1H-pyrrole	burnt sugar[2]	C6
Thiophenes	2-Acetyl-3-ethylthiophene		C178
	3-Thiophenecarboxaldehyde	sweet, almond[1]	C206

1.Burdock, 2010; 2.Flament, 2002;

Table 4.9 Least square means for GC volatile compounds for four commercial coffee blends.

Chemical Category	Volatile Compounds	Sensory Notes	Code	P value[e]	Commercial Coffee Blends[d]			
					Breakfast[d]	Classic[d]	Colombia[d]	Black[d]
Acids	Acetic acid	sour pungent[1]	C155	0.01	0[b]	4055[b]	67891[a]	1106[b]
Alcohols	2-Methoxy benzeneethanol	peach[1]	C24	0.04	137144[ab]	144614[ab]	89621[b]	203514[a]
Aldehydes	2-Butenal		C247	0.03	2862[ab]	429[b]	5930[a]	0[b]
	Hexanal	fruity, grassy[2]	C97	0.02	67076[a]	62458[a]	8833[b]	27467[ab]
Alkanes	Bicyclo[3.3.1]nonane		C129	0.03	0[b]	0[b]	3586[b]	25796[a]
Alkenes	1-Formylcyclopentene		C58	0.006	3742[b]	6782[b]	23210[a]	3398[b]
	2,3-Dimethyl-1,3-heptadiene		C271	0.01	0[b]	0[b]	16375[a]	0[b]
	3-Ethyl-2-hydroxy-2-cyclopenten-1-one		C63	0.007	1762[b]	0[b]	36849[a]	8691[b]
	3-Methyl-1,3-butadiene		C173	0.01	1292[b]	1086[b]	9142[a]	1627[b]
	3-Methoxy-5-methy-l-2-cyclopenten-1-one		C204	0.01	0[b]	0[b]	7444[a]	2867[ab]
	4-(2-Furanyl)-3-buten-2-one	sweet, spicy[2]	C183	0.001	505[b]	668[b]	5953[a]	1328[b]
	Dicyclobutylidene oxide		C28	0.03	7471[b]	24540[ab]	15560[ab]	32376[a]
Benzenes	4-Ethenyl-1-2-dimethoxy benzene		C126	0.003	2106[b]	5371[b]	15839[a]	5697[b]
Furans	2-Butanoyl furan		C269	0.02	0[b]	0[b]	7887[a]	0[b]
	2-Furancarboxaldehyde	caramel[2]	C10	0.0002	2062766[b]	2390310[b]	3840727[a]	2008049[b]
	2-Furancarbonitrile		C65	0.002	1232[b]	1110[b]	0[b]	4940[a]
	2-[(Methyldithio)methyl] furan	meaty/roasted[2]	C95	<.0001	41820[b]	55466[ab]	15252[c]	77003[a]
	2-2'-Bifuran	medicinal[2]	C119	0.0002	41529[b]	33437[b]	94196[a]	35989[b]
	2-(2-Furanylmethyl)-5-methyl-furan	green cooked, earthy[2]	C33	0.009	100650[b]	151844[ab]	208287[a]	159277[a]
	2-2'-Methylenebis furan	caramel, earthy[2]	C38	0.02	381732[b]	552619[ab]	565140[ab]	691140[a]

Table 4.9 Continued

Chemical Category	Volatile Compounds	Sensory Notes	Code	P value[e]	Commercial Coffee Blends[d]			
					Breakfast[d]	Classic[d]	Colombia[d]	Black[d]
Furans	2-(2-Propenyl)-furan		C8	0.001	99993c	154298b	214844a	165443ab
	2,3-Dihydro-6-methylthieno [2,3c]furan	burnt, smoky[2]	C75	0.02	145369[b]	311943[a]	201691[b]	193790[b]
	2,5-Dimethyl-3-ethylfuran		C249	0.001	684[b]	11071[a]	444[b]	0[b]
	5-Methyl-2-furancarboxaldehyde	caramel[2]	C66	0.01	1465282[b]	1333111[b]	2373411[a]	10711504[b]
Ketones	1-(2-Hydroxyphenyl) ethanone	sweet, floral[2]	C266	0.006	0[b]	397[b]	3347[a]	0[b]
	2,3-Hexanedione	sweet, buttery[1,2]	C76	0.005	0[c]	5286[bc]	41130[a]	24252[ab]
	2,3-Pentadnedione	sweet[2]	C17	0.001	96443[b]	270280[a]	90104[b]	142600[b]
Oxepines	2,7-Dimethyl oxepine		C136	0.03	27004[b]	78051[a]	48718[ab]	59625[ab]
Phenols	2-Methoxy phenol	smoky, phenolic[2]	C45	0.04	206770[ab]	209041[ab]	142039[b]	293071[a]
Pyrazines	2-Etheyl-5-methyl pyrazine	coffee[2]	C163	0.04	6986[a]	1421[b]	0[b]	1738[b]
	2,5-Dimethyl pyrazine	nutty[2,] roasted[2,4]	C140	0.0002	233572[a]	514396[a]	123935[b]	91296[b]
	3-Ethyl-2,5-dimethyl-pyrazine	hazelnut[2]	C49	0.02	149473[a]	146778[a]	59123[b]	133464[a]
	6,7-Dihydro-5-methyl-cyclopentapyrazine	hazelnut/roasted[3]	C207	0.04	4428[a]	602[b]	0[b]	482[b]
	Ethyl pyrazine	nutty[2], roasted[2,5]	C106	0.002	361603[a]	430418[a]	173836[b]	181340[b]
Pyridines	2-Methyl pyridine	hazelnut[2]	C194	0.02	520[b]	0[b]	0[b]	11110[a]
	4,6-Dimethylpyridin-2(1H)-one		C270	0.003	0[b]	0[b]	18815[a]	0[b]
	Pyridine		C51	0.001	963511[bc]	1140365[ab]	577740[c]	1561872[a]
Pyrimidines	Pyrimidine	burnt, smoky[2]	C145	0.04	39984[ab]	94393[a]	8695[b]	35767[ab]
	4,6-Dimethyl pyrimidine		C52	0.04	0[b]	141893[ab]	0[b]	273332[a]
Pyrroles	1H-Pyrrole	warm, hay-like[2]	C2	0.008	116375[bc]	176932[ab]	82578[c]	212025[a]
	1-Methyl-1H-pyrrole	fruity[2]	C7	0.03	529542[a]	678047[a]	202333[b]	502286[ab]

Table 4.9 Continued

Chemical Category	Volatile Compounds	Sensory Notes	Code	P value[e]	Commercial Coffee Blends[d]			
					Breakfast[d]	Classic[d]	Colombia[d]	Black[d]
Pyrroles	1-Ethyl-1H-pyrrole-2-carboxaldehyde	burnt/roasted[2]	C111	0.01	17881[ab]	25616[a]	0[c]	9991[bc]
	2,5-Dimethyl-1H-pyrrole		C112	0.02	19243[ab]	21851[ab]	6470[b]	31979[a]
Thiophenes	3-Methyl thiophene	winey/ashy[2]	C146	0.03	9146[b]	29871[a]	10962[b]	9539[b]

1.Burdock, 2010; 2.Flament, 2002; 3.Akiyama, 2005; 4.Akiyama, 2005; 5.Maeztu, 2001.

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

[d] Breakfast = Folgers® Breakfast blend, Classic = Folgers® Classic roast, Colombia= Folgers® 100% Colombia, Black= Folgers® Black silk

[e] P value from Analysis of Variance table

Table 4.10 Least square means for GC volatile compounds for four brew methods.

Chemical Category	Volatile Compounds	Sensory Notes	Code	P value[e]	Brew Method[d]			
					Cold[d]	Drip[d]	French[d]	Pour[d]
Aldehydes	2-Butenal		C247	0.01	0[b]	6869[a]	1046[b]	1126[b]
	2-Methyl-3(2-furyl)acrolein	woody, spicy[1]	C115	0.01	3991[b]	17878[a]	10115[ab]	10042[ab]
	α-Ethylidene benzeneacetaldehyde	green, floral[2]	C86	0.02	6504[c]	17078[a]	14966[ab]	8728[bc]
Alkenes	1,3-Pentadiene		C61	0.003	3954[a]	282[b]	0[b]	591[b]
	3-Methoxy-5-methyl-2-cyclopenten-1-one	caramel[1]	C204	0.03	0[b]	0[b]	4670[ab]	5641[a]
Amines	4-Phenylbut-3-ynylamine		C226	0.003	6772[a]	0[b]	0[b]	1849[b]
Esters	2-Hydroxy-methyl ester-benzoic acid		C25	0.04	50273[b]	110666[a]	78527[ab]	59074[b]
Furans	2-Ethenyl benzofuran		C184	0.03	1758[b]	17446[ab]	21064[a]	1576[b]
	2-[(Methyldithio)methyl] furan	meaty, roasted[2]	C95	<.0001	15002[c]	68321[a]	67717[a]	38500[b]
	2-Pentyl furan	fruity, green[1]	C133	0.0004	2252[c]	21092[b]	41481[a]	8640[bc]
	2-Vinyl-5-methylfuran		C118	0.005	133389[b]	302946[b]	557986[a]	271299[b]
	2-(2-Propenyl)-furan		C8	0.001	121056[b]	132098[b]	221734[a]	159690[b]
	2-2'-Bifuran	medicinal[2]	C119	0.02	27639[b]	51129[ab]	55369[a]	71013[a]
	2-(2-Furanylmethyl)-5-methyl-furan	earthy[2]	C33	0.01	103456[b]	199979[a]	171029[a]	145563[ab]
	2,2'-Methylenebis furan	caramel, earthy[2]	C38	0.0005	297212[c]	619534[ab]	742700[a]	531185[b]
	2,3-Dihydro-6-methylthieno [2,3c]furan	burnt, smoky[2]	C75	0.01	113953[b]	245974[a]	298973[a]	193892[ab]
	3-Pentyl furan	jasimine[2]	C41	0.002	14794[c]	53474[a]	50577[ab]	30236[bc]
Indoles	1-Methyl-1H-indole		C174	0.03	0[b]	3638[ab]	9747[a]	1772[b]
	2,3-Dihydro-1-methyl-1H-indole-5-carboxaldehyde		C148	0.02	0[b]	3639[a]	3822[a]	0[b]
Ketones	1-(2-Thienyl) ethanone		C94	0.03	23019[ab]	31135[a]	22323[ab]	9589[b]

Table 4.10 Continued

Chemical Category	Volatile Compounds	Sensory Notes	Code	P value[e]	Brew Method[d]			
					Cold[d]	Drip[d]	French[d]	Pour[d]
Ketones	2,3-Hexanedione	sweet, buttery[1,2]	C76	0.02	39217[a]	10803[b]	3935[b]	16714[ab]
	5-Methyl-3-heptanone		C121	0.001	16732[a]	1520[b]	0[b]	0[b]
Oxepine	2,7-Dimethyl oxepine		C136	0.0005	29621[b]	4177[b]	101845[a]	40756[b]
Phenols	2-Methoxy-4-vinylphenol	spicy[2]	C13	0.04	197718[b]	353039[a]	294477[ab]	179716[b]
	Nona-3,5-dien-2-one		C224	0.02	5743[a]	0[b]	0[b]	1475[b]
Pyrans	2H-1-Benzopyran		C151	0.03	787[b]	13149[a]	0[b]	3667[ab]
Pyrazines	2-Ethenyl-5-methyl pyrazine	coffee[2]	C163	0.04	0[b]	4116[ab]	6030[a]	0[b]
Pyridinamines	5-Methyl-2-pyridinamine		C72	0.01	178200[a]	61276[b]	37050[b]	0[b]
Pyrimidines	2-(Carboxymethylthio)-pyrimidine		C177	0.01	0[b]	4358[a]	131[b]	0[b]
	4,6-Dimethyl pyrimidine		C52	0.02	94931[ab]	0[b]	250554[a]	69741[b]
Pyrroles	1-Furfuryl-2-formyl pyrrole		C110	0.01	1919[c]	17689[a]	14757[ab]	5959[bc]
	1-(2-Furanylmethyl)-1H-pyrrole		C5	0.001	378704[b]	598817[b]	581179[a]	345661[b]
	1-Ethyl-1H-pyrrole-2-carboxaldehyde	burnt/roasted[2]	C111	0.03	11752[ab]	10710[b]	4274[b]	26751[a]
	1-(5-Methylfurfuryl)-pyrrole	fruity, earthy[2] roasty[3]	C109	0.01	4546[b]	26003[a]	11325[b]	7737[b]
	N-Methyl-2,5-dimethylpyrrole		C43	0.04	5012[a]	997[b]	3773[ab]	1234[b]
Thiophenes	2-Acetyl-3-ethylthiophene		C178	0.01	0[b]	15478[a]	0[b]	12949[a]
Sulfur compounds	Dimethyl trisulfide	green, burnt[2]	C107	0.004	42353[b]	76225[b]	166016[a]	99233[b]

1.Burdock, 2010; 2.Flament, 2002; 3.Holscher, 1990.

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

[d] Cold = cold brew, Drip = drip brew, Pour = pour over, French = French press

[e] P value from Analysis of Variance table

Correlations Between Volatile Compounds and Descriptive Sensory Analysis

To see and further understand relationships between volatile compounds and descriptive trained panel attributes across coffee samples, partial least squares regression biplots were used (Figure 4.5 - Figure 4.12). Figure 4.5 and Figure 4.6 showed the correlations of all 271 volatile compounds and descriptive sensory attributes across 16 coffee samples. To make the correlations even clearer, we also analyzed those volatile compounds which differed ($P < 0.05$) across interactions of coffee types and brew methods as well as only coffee types and only brew methods, respectively (Figure 4.7- Figure 4.12).

Across all eight partial lease squares regression biplots, Colombia coffees were always separate from the other three coffee types especially Colombia Cold Brew. From Figure 4.7 to Figure 4.12, Colombia Cold Brew was always on the negative side of axes t1, clustered with sweet, overall sweet sensory notes as well as 2,3-hexanedione (C76). Among the four brew methods, cold brewed coffees were always separated from the other three brew method coffees. Breakfast Blend Cold Brew, Classic Roast Cold Brew, and Black Silk Cold Brew were always clustered together with fruity non-citrus sensory notes. 2,7-dimethyl oxepine (C136) was found highly related to Black Silk French Press coffee sample across all eight biplots.

Flament (2002) clarified that acetaldehyde, together with propanal, was responsible for fruity and green odor in coffee brew. 2-methyl-propanal (C104) was found clustered with fruity non-citrus flavor (Figure 4.6) and also was responsible for the chocolate and malty odor in coffee brew (Semmelroch & Grosch, 1996). Hexanal (C97) has been described as the main chemical compound responsible for green notes by Flament (2002) but was found related to dark chocolate, grain and fruity non-citrus aroma (Figure 4.5). 2-methyl-butanal (C26) and 3-methyl-butanal (C27) were associated with petroleum & fruity-dark aroma (Figure 4.5) and malty (Holster, 1990). Octanal (C267) was associated with petroleum-like flavor (Figure 4.6) and orange-like (López-Galilea, 2006).

Caporaso et al. (2014) found that furans which do not contain sulfur are generally associated with nutty, caramel, smoke, floral, and ethereal odor, while those containing sulfur are responsible for sulfur, garlic, or toasty odor note. 2-[(methylthio)methyl]-furan (C35) was found closely related to musty/earthy, smoky, and sour aromas; acrid, bitter, sour, and burnt flavors; overall impact and bitter aftertaste in this study (Figure 4.5 & Figure 4.6). Akiyama (2005) also found it related to roasted/smoke aroma.

In this study, 2-ethyl-6-methylpyrazine (C48), 2-ethyl-3,5-dimethylpyrazine (C49) were found closely related to cardboard flavor. 2-ethyl-3,5-dimethyl-pyrazine (C105) was clustered with fruity, non-citrus flavor (Figure 4.6) and was also found related to earth/hazelnut/roasted (Sanz, 2002; Akiyama, 2005; Maetzu, 2001; Czeny, 1999; Holster, 1990). Ethyl-pyrazine (C106) was found associated with grain and fruity non-citrus aroma (Figure 4.5) and peanuts/roasted by Maeztu (2001). 2,5-dimethyl-pyrazine (C140) was found clustered with dark chocolate aroma and woody flavor (Figure 4.5 & Figure 4.6) and hazelnut/roasted by Akiyama (2005). Nutty aroma, smoky aroma, and dark chocolate flavor were found related to 2-(n-propyl)-pyrazine (C193)

(Figure 4.5 & Figure 4.6). López-Galilea (2006) found 2-(n-propyl)-pyrazine was associated with herbal. Woody flavor was found related to 6,7-dihydro-5-methyl-cyclopentapyrazine (C207; Figure 4.6).

To make the correlations even clearer, we also analyzed those volatile compounds which differed ($P < 0.05$) across interactions of coffee types and brew methods as well as only coffee types and only brew methods, respectively (Figure 4.7-Figure 4.12).

2,3-hexanedione (C76) and 2,7-dimethyl oxepine (C136) differed across interactions of coffee types and brew methods ($P < 0.05$), coffee types ($P < 0.05$), and brew methods ($P < 0.05$). Viani et al. (1965) identified 2,3-hexanedione (C76) after steam distillation of roasted coffee. Procida et al. (1997) characterized this compound only discovered in the headspace of a roasted coffee but not in any of the studied green coffees. 2,3-hexanedione has a powerful, creamy-sweet odor (Flament, 2002), the flavor is fatty, fruity, pear-like (Flament, 2002). Across Figure 4.5 - Figure 4.12, 2,3-hexanedione (C76) was clustered with Cold Brew coffee especially Colombia Cold Brew showed a high relation with fruity, floral aroma notes as well as sweet flavor notes.

2-acetyl-3-ethylthiophene (C178) which differed ($P < 0.05$) across interactions of coffee types and brew methods as waell as brew methods ($P < 0.05$) was highly related to Colombia Drip showing a high relationship with main coffee flavor attributes including overall impact, bitter, burnt, sour, roasted, ashy, etc. 3-ethyl-2-hydroxy-2-cyclopenten-1-one (C63) differed ($P < 0.05$) across interactions of coffee types and brew methods as well as coffee types ($P < 0.05$) and was clustered with Colombia Drip and caramel aroma notes (Figure 4.7 - 4.10). Burdock (2010) described 3-ethyl-2-hydroxy-2-cyclopenten-1-one a compound often employed a caramel flavor in food as well as exhibited flavor-enhancing characteristics.

Across Figure 4.8 - Figure 4.12, there were 12 volatile compounds that differed ($P < 0.05$) across coffee types and differed ($P < 0.05$) across brew methods. 3-methoxy-5-methyl-2-cyclopenten-1-one (C204) was clustered with Colombia coffees except Colombia Cold Brew and showed beany aroma notes. 2-2'-bifuran (C119) was found in reactions of serine and threonine with sucrose (Baltes and Bochmann, 1987) and was highly related to beany aroma notes. According to Winter et al. (1976a), when tasted in a neutral, soluble coffee base, 2-2'-bifuran showed medicinal, camphor, and ricy flavor. 2-(2-furanylmethyl)-5-methyl-furan (C33) and 2-(2-propenyl)-furan (C8) were highly related with mouth drying astringent. Baltes and Bochmann (1987) found 2-(2-furanylmethyl)-5-methyl-furan (C33) when heating serine and threonine with sucrose. Winner et al. (1976) found it imparts to a liquorice-like note in coffee. 2-2'-methylenebis furan (C38), identified in the products of thermal degradation of cysteine and xylose in tributyrin (Ledl and Severin, 1973), was highly related to roasted, ashy, musty earthy, and burnt notes. It was also described by Shibamoto (1977) as having a caramellic odor and Flament (2002) as an earthy and mushroom flavor. 2,3-dihydro-6-methylthieno-[2,3c]furan (C75) was also highly related to roasted, ashy, musty earthy, and burnt notes and reported had a rubbery, burnt note by Flament (2002). 2-etheyl-5-methyl pyrazine (C163) was highly related with cardboard note and Flament (2002) reported it imparted a coffee-like taste to a sugar syrup (20ppm). 1-ethyl-1H-pyrrole-2-

carboxaldehyde (C111) was clustered with Pour Over coffees except for Colombia Pour Over and dark chocolate and grain aroma notes. Winter et al. (1976b) gave it a burnt, roasted flavor description.

In Figure 4.9 and Figure 4.10, Folgers® 100% Colombia coffee was most separated from other three coffee types. Folgers® 100% Colombia coffee was high in 2-butenal (C247), 1-(2-hydroxyphenyl)-ethanone (C266; beany aroma), 2,3-hexanedione (C76; caramelized and dark green aroma). Folgers® Breakfast blend coffee was closely related to petroleum aroma and high in 2-pentyl furan (C133; fruity non-citrus aroma) and high in 3-methyl-thiophene (C146). Folgers® Classic roast was high in bicyclo[3.3.1]nonane (C129; dark chocolate flavor) and closely related to stale and cocoa aroma. Folgers® Black silk was high in dicyclobutylidene oxide (C28) (musty/earthy flavor) and 2,7-dimethyl-oxepine (C136; nutty aroma).

In Figure 4.9 and Figure 4.10, Cold Brew was most separated from the other three brew methods which matched the finding before. Cold brewed coffee was found high in 2,3-hexanedione (C76; dark green aroma), 5-methyl-3-heptanone (C121; sweet note). Pour over brewed coffee was high on N-methyl-2,5-dimethylpyrrole (C43; dark fruity aroma), 2H-1-benzopyran (C151; musty dusty flavor). Coffee brewed using drip method showed high on 2-butenal (C247; beany aroma), 2-(carboxymethylthio)-pyrimidine (C177; woody aroma), pyridine (C51, cardboard aroma) and 2H-1-benzopyran (C151; musty dusty flavor) as well. French press brewed coffee was high on 2-(carboxymethylthio)-pyrimidine (C177; woody aroma).

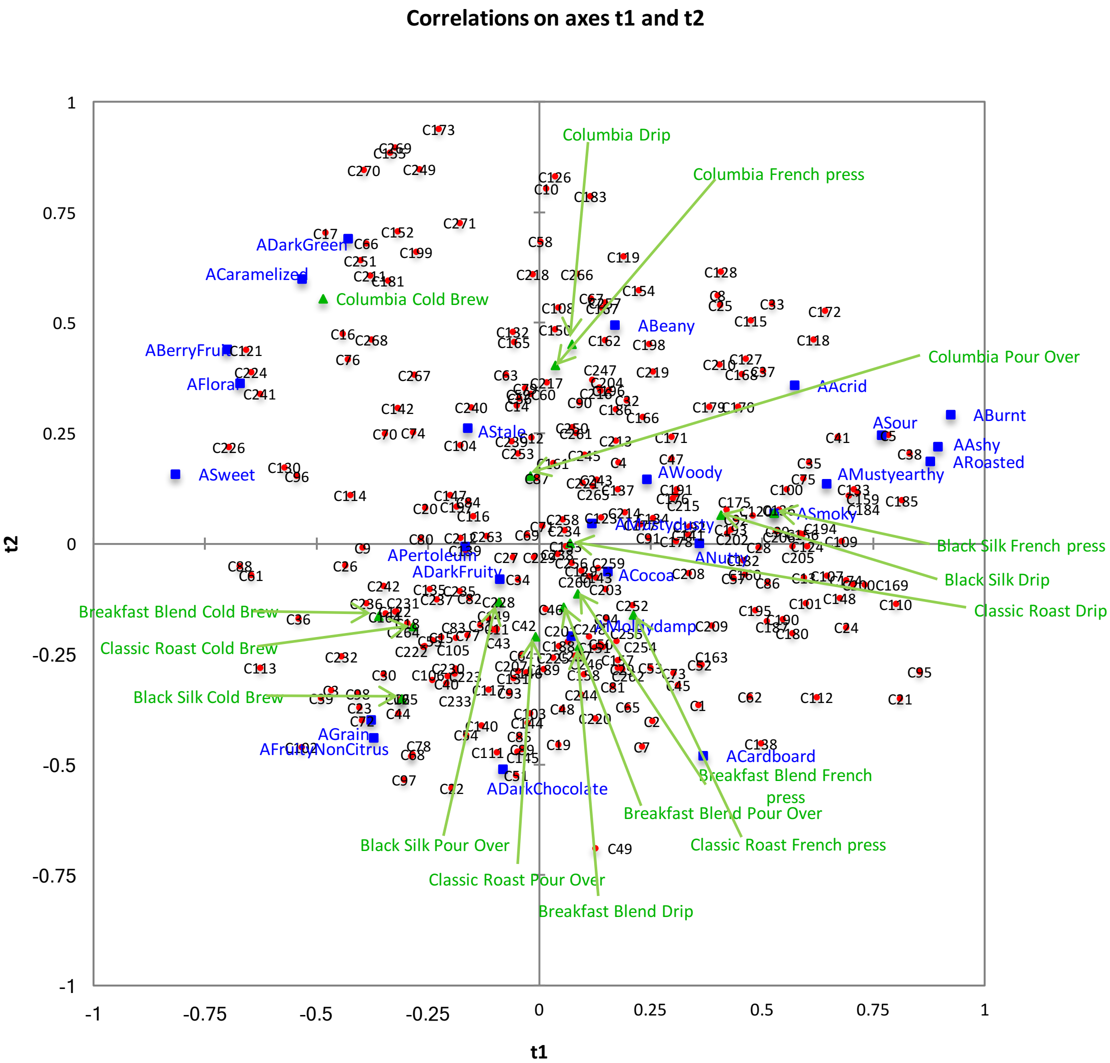

Figure 4.5 Partial least squares regression biplot for descriptive sensory aroma attributes (■), volatile compounds (●) and coffee samples (▲)

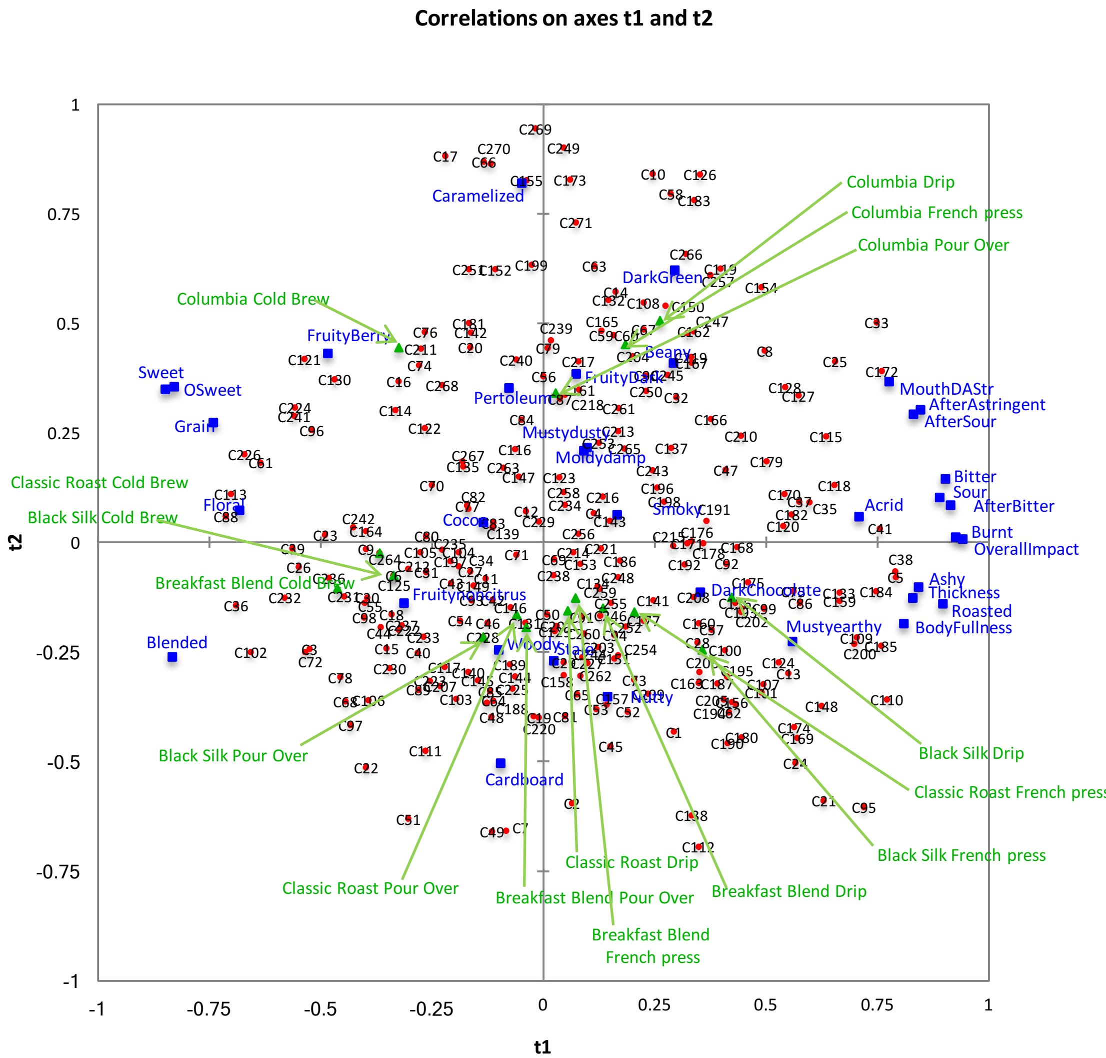

Figure 4.6 Partial least squares regression biplot for descriptive attributes (flavor, texture, and aftertaste) (■), volatile compounds (●) and coffee samples (▲)

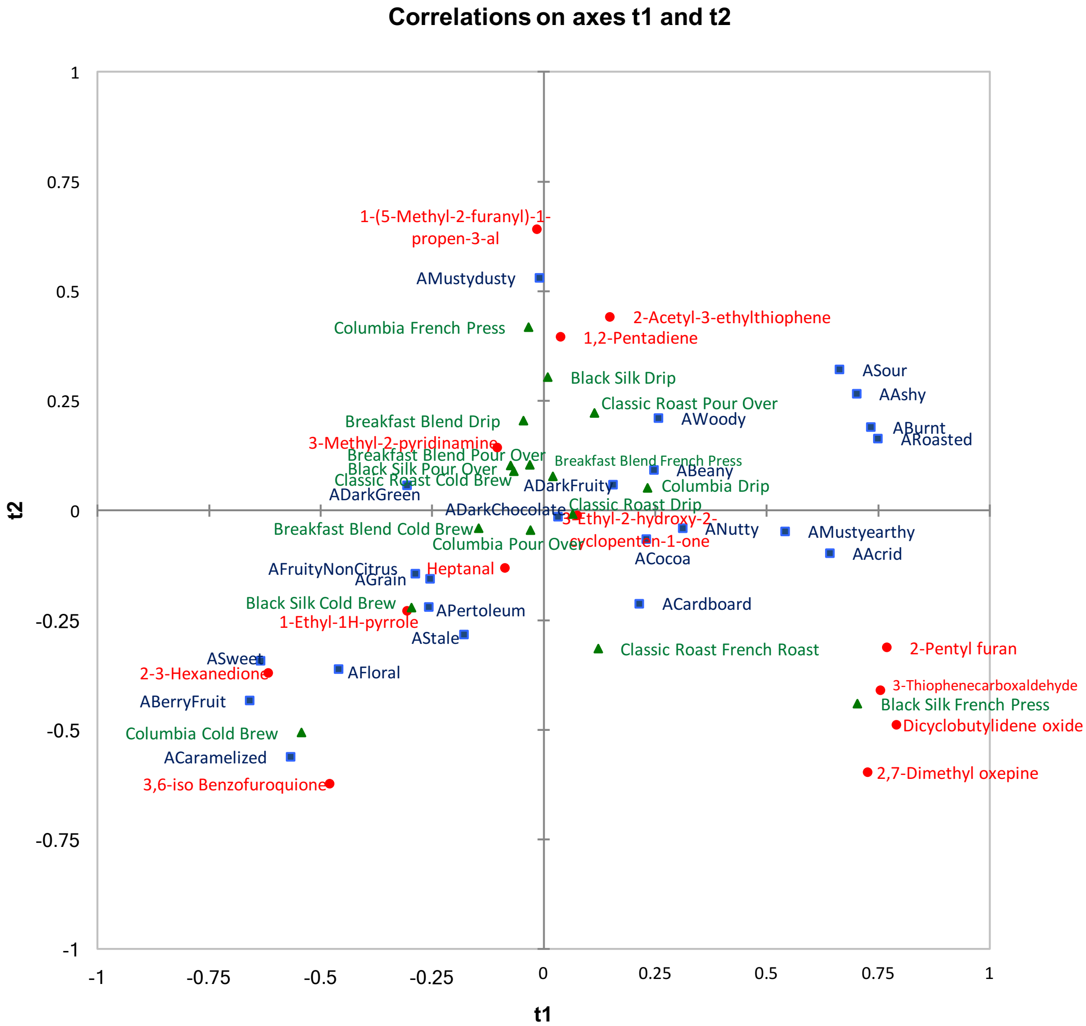

Figure 4.7 Partial least squares regression biplot for volatile compounds which differed across the interactions of coffee types and brew methods (●), descriptive sensory aroma attributes (■), and coffee samples (▲)

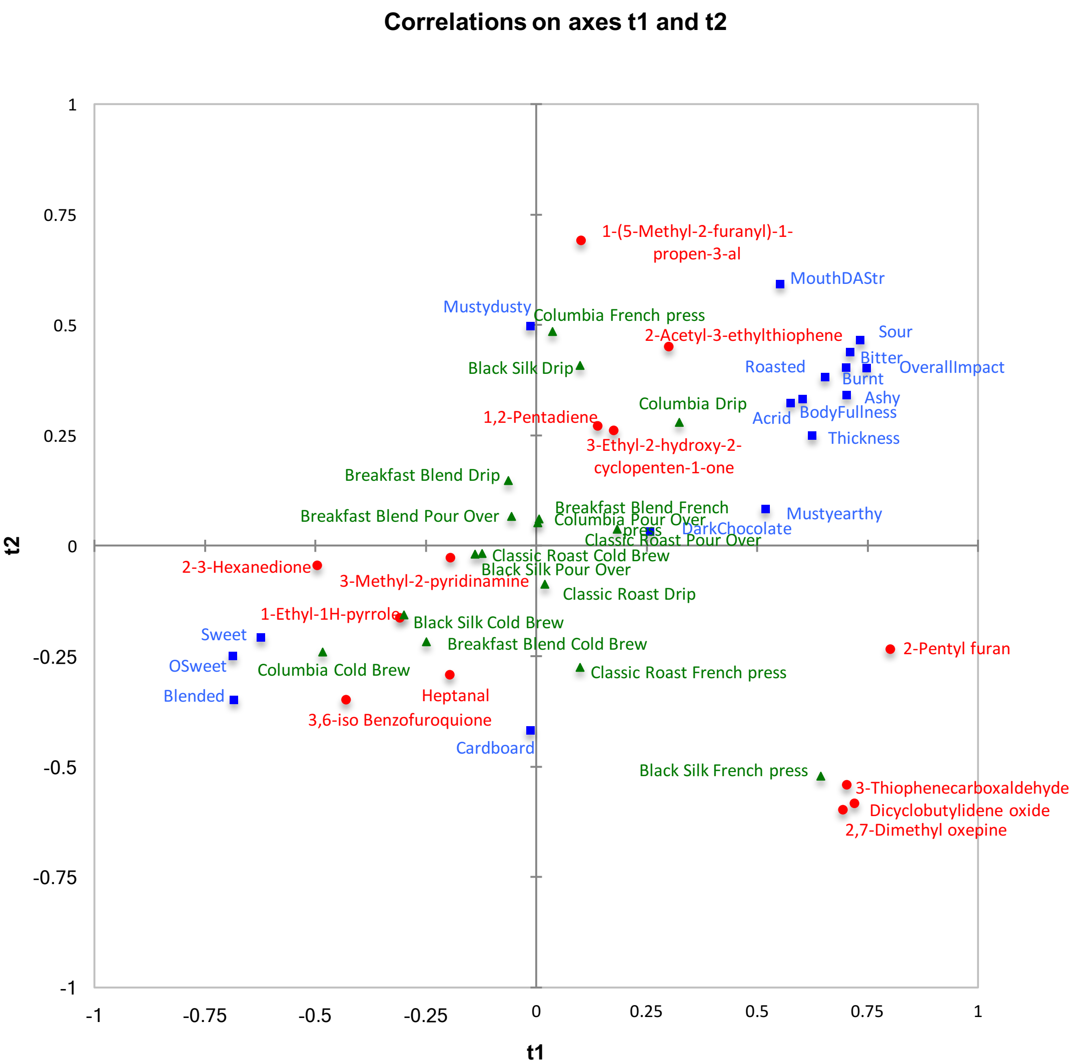

Figure 4.8 Partial least squares regression biplot for volatile compounds which differed across the interactions of coffee types and brew methods (●), descriptive sensory attributes (flavor, texture and aftertaste) (■), and coffee samples (▲)

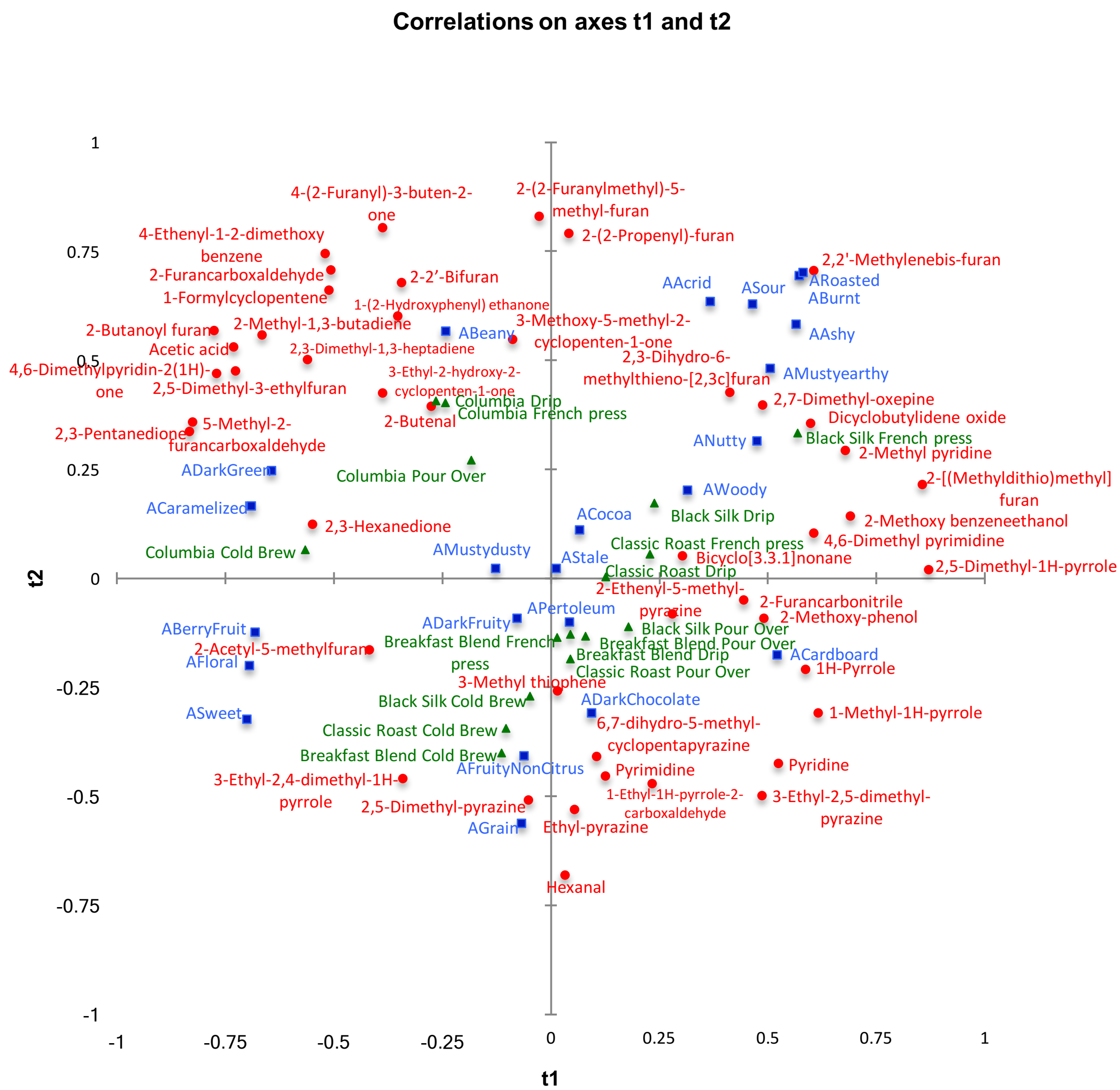

Figure 4.9 Partial least squares regression biplot for volatile compounds which differed across coffee types (●), descriptive sensory aroma attributes (■), and coffee samples (▲)

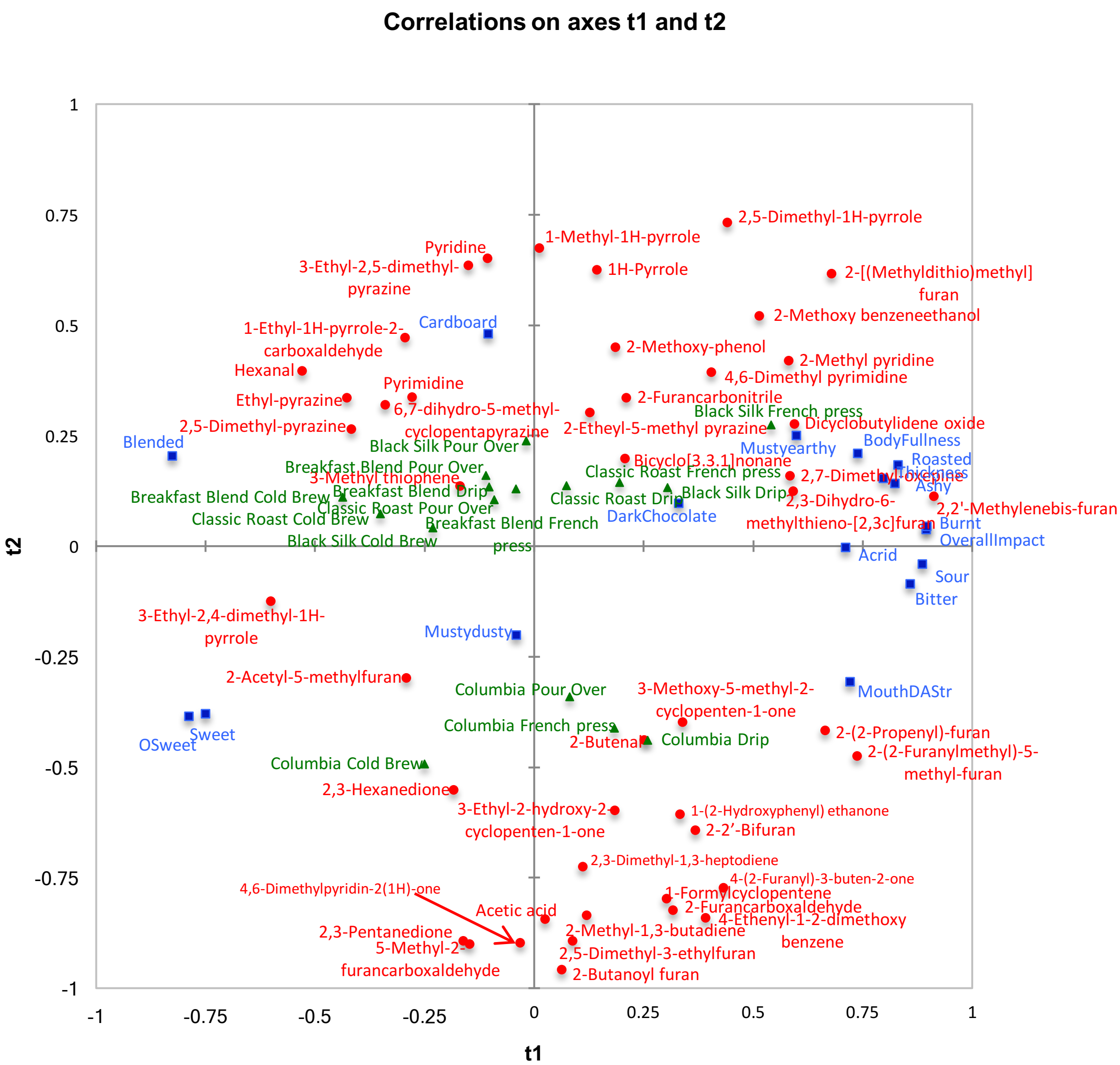

Figure 4.10 Partial least squares regression biplot for volatile compounds which differed across coffee types (●), descriptive sensory attributes (flavor, texture and aftertaste) (■), and coffee samples (▲)

Correlations on axes t1 and t2

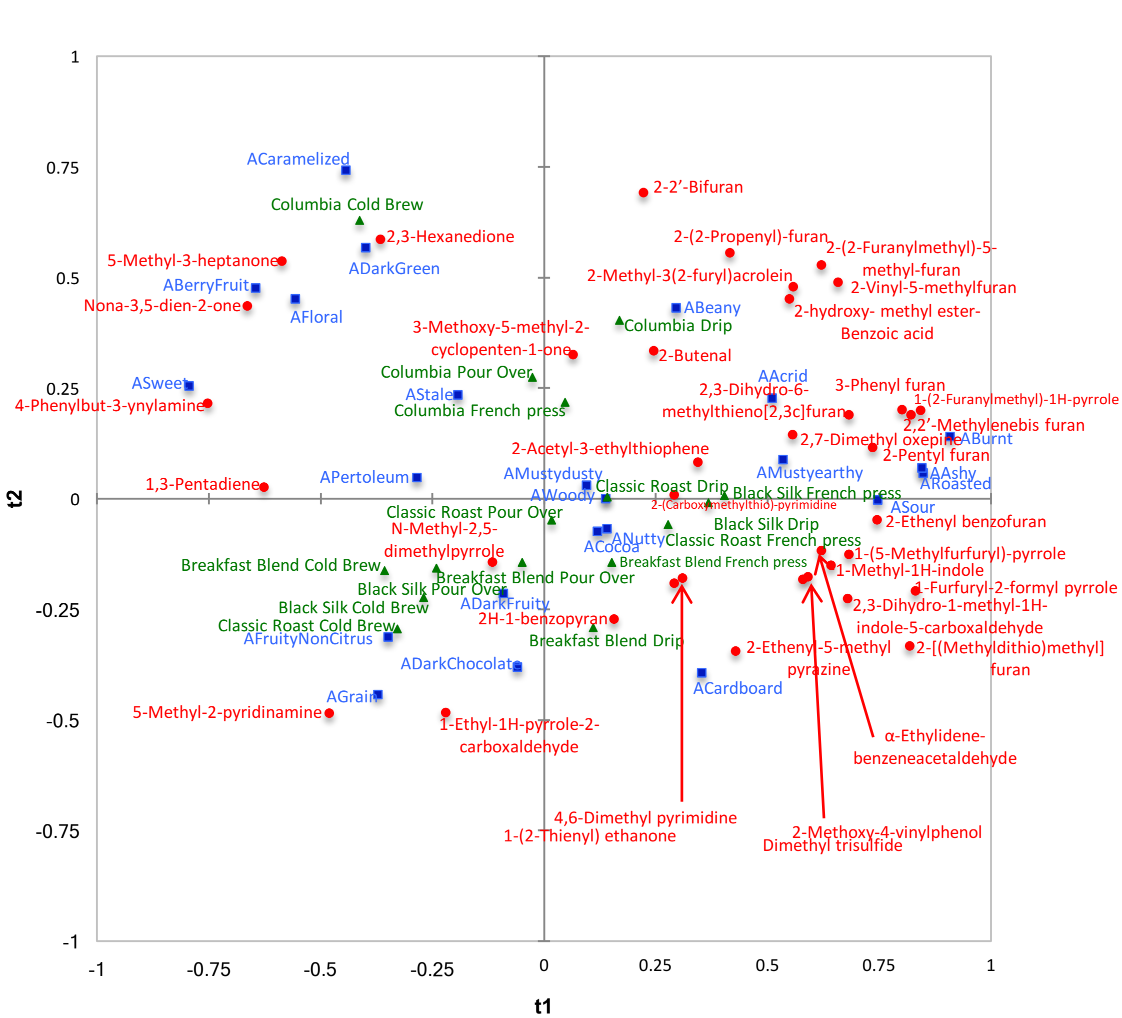

Figure 4.11 Partial least squares regression biplot for volatile compounds which differed across brew methods (●), descriptive sensory aroma attributes (■), and coffee samples (▲)

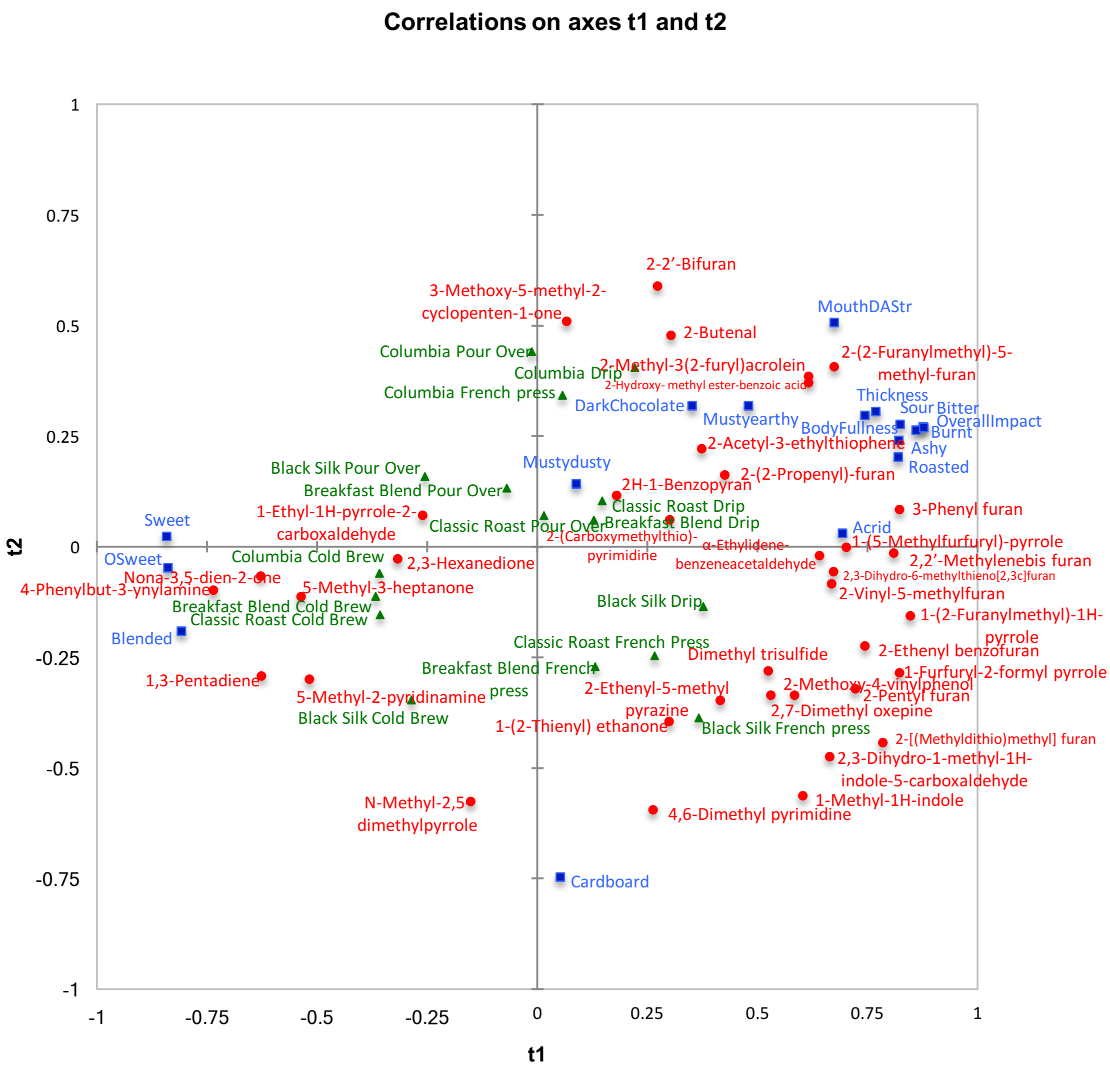

Figure 4.12 Partial least squares regression biplot for volatile compounds which differed across brew methods (●), descriptive sensory attributes (flavor, texture and aftertaste) (■), and coffee samples (▲)

CHAPTER V

CONCLUSION

The results showed that coffee types and brew methods did affect coffee aroma and flavor. Cold brew method produced the mildest coffee among the four brew methods while drip produced a much stronger coffee. The sensory aroma and flavor differences between different coffee types were not as great as differences between brew methods. However, Folgers® 100% Colombia coffee had a higher amount of volatile compounds, such as 2-butenal (beany aroma), and 1-(2-Hydroxyphenyl)-ethanone (beany aroma). Cold brewed coffee especially cold brewed Folgers® 100% Colombia coffee was high in fruity and floral aromas, and sweet and overall sweet flavors as well as 2,3-hexanedione. These results indicated that coffee from the cold brew method was more fruity, floral and sweet whereas coffee from the drip or French press method were more roasted, burnt, and ashy.

In this research, some chemical flavor compounds were found that differentiated coffee sensory flavors. Volatile compounds 2,3-hexanedione was an indicator of fruity, floral, and sweet notes. 2-acetyl-3-ethylthiophene, 2-2'-methylenebis furan, and 2,3-dihydro-6-methylthieno-[2,3c]furan were highly related to roasted, burnt, ashy flavors. Caramel flavor was most highly related to 3-ethyl-2-hydroxy-2-cyclopenten-1-one while 3-methoxy-5-methyl-2-cyclopenten-1-one was highly related to beany. 2-etheyl-5-methyl pyrazine was highly related to cardboard flavors.

The preparation method is a critical factor affecting coffee flavor and aroma. Based on the desired flavor profile, suggestions on consumer labels for brew method may improve consumer satisfaction. When conducting research to examine flavor and aroma effects from coffee beans, standardization of roast level and brew method would be imperative. Descriptive sensory evaluation and gas chromatography /mass spectrometry systems can be effective and quick methods to discriminate and screen aromas and flavors in coffee.

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APPENDIX A

BALLOT FOR SENSORY TEST

Attribute		253	298
Aroma	Roasted		
	Burnt		
	Sweet		
	Sour		
	Ashy		
	Acrid		
	Smoky		
	Musty/earthy		
	Woody		
	Grain		
	Dark Chocolate		
	Cocoa		
	Caramelized		
	Fruity, Dark		
	Fruity, Berry		
	Fruity, non-citrus		
	Floral		
	Dark Green		
	Cardboard		
	Nutty		
	Beany		
	Petroleum-like		
	Musty/dusty		
	Stale		
	Moldy/damp		
Flavor	Overall Impact		
	Blended		
	Body/Fullness		
	Mouth Drying/Astringent		
	Thickness		
	Bitter		
	Roasted		
	Burnt		
	Overall Sweet		
	Sweet		
	Sour		

	Ashy		
	Acrid		
	Smoky		
	Musty/earthy		
	Woody		
Flavor	**Grain**		
	Dark Chocolate		
	Cocoa		
	Caramelized		
	Fruity, Dark		
	Fruity, Berry		
	Fruity, non-citrus		
	Floral		
	Dark Green		
	Cardboard		
	Nutty		
	Beany		
	Petroleum-like		
	Musty/dusty		
	Stale		
	Moldy/damp		
	Bitter Aftertaste		
	Sour Aftertaste		
	Astringent Aftertaste		