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Evolution of Sensory Aroma Attributes from Coffee Beans to Brewed Coffee

Natnicha Bhumiratana, Koushik Adhikari*, Edgar Chambers IV

Sensory Analysis Center, Kansas State University, Manhattan, KS 66506, U.S.A.

*Corresponding author: Koushik Adhikari, Sensory Analysis Center, Kansas State University, Manhattan, KS 66506, U.S.A.

E-mail: koushik@k-state.edu

Abstract

This study investigated the impact of degree of roasting, grinding, and brewing on the evolution of coffee aroma in green coffee beans from Ethiopia, Hawaii, and El Salvador. Using a highly-trained descriptive panel, 15 aromatic sensory attributes were identified and quantified in green beans, roasted beans (light, medium, and dark), ground coffee, and brewed coffee. Analysis of variance (ANOVA) and principal components analysis (PCA) were done separately for each preparation stage/step. The ANOVA showed that green beans had low coffee-related characteristics and were high in beany, green, musty/earthy, and sour aromatics, all of which carried through to the final brews. In general, the light roast was perceived to be sweeter in all stages and the darker roasts attained higher intensity of the typical 'coffee' attributes with which coffee consumers might like (coffee, roasted, burnt/acrid, and ashy/sooty). The aroma profiles generated were more influenced by the preparation stages and degrees of roasting than the coffee varieties.

Keywords: Coffee origin, aroma, descriptive analysis, roast levels

1. Introduction

Odello and Lavaroni (2009) showed evidence that consumers are interested in 'pure' coffee or coffee of a single origin. Although they found that consumers were unable to distinguish coffee blends from single origin coffees, they seemed to have a substantial interest in single origin coffee. In order to understand whether this consumption trend towards single origin coffees is based on real differences in sensory aspects of coffees or is more related to other perceptual issues, the industry needs to investigate the sensory characteristics of this so-called 'pure' coffee to develop a better understanding of this product category.

Aromatic components are particularly important in coffee beverages as they are the main constituents of the sensory experience of coffee drinkers. Illy & Viani (2005) summarized that there are six factors that affect the sensory properties of coffee: plant varieties, growing region/conditions, processing methods (from coffee cherries to green coffee bean), roasting levels, grinding size, and brewing methods. Extensive studies have been conducted since the beginning of 1900's to discover the volatile compounds responsible for coffee aroma and flavor in roasted bean, ground coffee, and brewed coffee (Semmelroch & Grosch, 1996; Czerny, Mayer, & Grosch, 1999; Sarrazin, Le Quere, Gretch, & Liardon, 2000). Many studies have investigated the impact of coffee origin, degree of roasting and roasting time and temperature combinations on the formation of volatile compounds responsible for the coffee flavors and aromas (Mayer, Czerny, & Grosch, 1999; Schenker, Heinemann, Huber, Pompizzi, Perren, & Escher, 2002; Baggenstoss, Poisson, Kaegi, Perren, & Escher, 2008). However, finding the relation between the content of the hundreds of volatile compounds present in coffee and the complex aroma of coffee is not an easy task (Nebesny & Budryn, 2006). Sensory analysis has become a useful tool for quality assessment of coffee beans and brews. A few previous studies

have evaluated some of the sensory attributes and overall acceptability of roasted coffee beans and brewed coffee with the intent of examining the effect of growing environments, coffee varieties, roasting methods and conditions, degrees of roasting, and storage conditions on these coffees (Nebesny & Budryn, 2006; Decazy, Avelino, Guyot, Perriot, Pineda, & Cilas, 2003; Ross, Pecka, & Weller, 2006).

However, no sensory research was found on the development of aroma in each stage of preparation, starting from green coffee bean to brewed coffee. This gap in research should be investigated because 1) each stage plays a significant role in the development of coffee aroma during the coffee brewing process, 2) sensory characteristics need to be identified and quantified because not all the present volatile compounds in a substance are perceived by humans. The concentration of a given compound must exceed the recognition threshold level in order to trigger the receptor response in the brain to generate an image of the aroma (Czerny et al., 2008; Grosch, 1998).

Green coffee beans are the raw material of coffee. The green beans contain the precursors of aroma volatiles that are developed during the roasting process. Different coffee varieties, growing conditions, and processing methods contribute to the distinctive aromatic compounds unique to each type/origin of green coffee. Although the aroma and flavors are characterized by the origin of green coffee, the roasting process controls the developmental progress of the volatile compounds, resulting in differences in complexity of coffee aroma with different roast degrees and conditions. 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. Starch in the bean converts to sugar and starts to caramelize as moisture escapes. Once the bean is heated to 205°C, pyrolysis

(thermal decomposition and chemical change) occurs. Carbon dioxide, aldehydes, ketones, ethers, acetic acid, methanol, oils, and glycerol are volatilized from the bean. Different volatile compounds break down at different temperatures, and as pyrolysis continues, the flavor and aroma of the coffee bean continue to develop and degrade (Sivetz & Desrosier, 1979; Illy & Viani, 2005; Yeretzian, Jordan, Badoud, & Lindinger, 2002). Grinding of roasted coffee beans is a method used to release the developed coffee aromatic compounds and brewing extracts the aromatic compounds from ground coffee into the final drink. A specific grind size is appropriate to certain brewing methods (Sivetz & Desrosier, 1979; Illy & Viani, 2005).

Not much work has been reported on evolution of aroma attributes from the green coffee bean stage to the brewed coffee stage. All forms of coffee are available in the retail for consumer purchase in the form of green coffee bean, whole roasted coffee bean, ground coffee, and brewed coffee drinks. Because coffee aroma is the major factor in purchase decision, it is crucial that the industry be able to understand the aroma attributes present in each stage, and also how the attributes develop during the process of making the coffee drink. The major objective of our study was to identify the change in aroma characteristics as a result of roasting, grinding and brewing processes in three coffee bean varieties. The effect of bean origin (El-Salvador, Hawaii and Ethiopia) and levels of roast (light, medium and dark) on the evolution of aroma attributes were also studied.

2. Materials and methods

2.1. Coffee Samples

Wet-processed green Arabica coffee varieties from three countries of origin were used to represent different single origin coffee varieties from different wet-processed Arabica coffee producing regions. The coffee beans selected are Hawaii Kona Lehuula Farm Typica, Ethiopia

Organic Wet-process Kebado, and El Salvador Siberia Estate Bourbon. All the green coffee samples were purchased from Sweet Maria's Home Roasting website (http://www.sweetmarias.com/index.php).

2.2. Sample preparation and serving

The amount of coffee sample to be evaluated is determined according to the brewing standard of Specialty Coffee Association of America (SCAA). For a standard 100 mL cup of brewed coffee, 4.9 g of ground coffee is recommended by the SCAA. Therefore, 4.9 g of each sample of green coffee, roasted coffee, and ground coffee and 100 mL of each sample of brewed coffee were presented to the panelists in a 414-mL glass snifter covered with a watch glass. The panelists cleansed their nasal passages between each sample by breathing through a warm clean cotton washcloth filter.

2.2.1. Roasting

Preliminary testing was done to assess the appropriate roasting time and temperature for each roast level (data not included). Each green coffee sample was roasted in a Hearthware i-Roast2 home coffee roaster (Model No. 40011; Hearthware Inc., Gurnee, IL, USA) to create light, medium, and dark roasts (Sivetz & Desrosier, 1979; Schenker et al., 2002; Yeretzian et al., 2002; Illy & Viani, 2005; Baggenstoss et al., 2008); Owen, 2009). The roaster was programmed to consist of 3 consecutive roasting temperature/time combinations to produce the assigned degree of roasting. For the light roast, coffee beans were roasted at 180°C for 3 min and 30 s and 205°C for 3 min. For the medium roast, coffee beans were roasted at 180°C for 3 min and 30 s.; 205°C for 4 min; and 238°C for 10 s. For the dark roast, coffee beans were roasted at 180°C for 3 min and 30 s.; 205°C for 4 min; and 238°C for 1 min. Once the roasting process was terminated, cool air was immediately blown into the chamber for 4 min to cool down the roasted

beans. The roasted coffee was then removed from the roaster and placed in a metal container to cool until it reached room temperature (22 ± 2 °C**).** The roasted samples were stored in 110-mL clear, stand up, odor-free, zippered plastic bags with a CO_2 de-gassing valve, also purchased from Sweet Maria's. All samples were allowed to rest for at least 24 hours prior to testing.

2.2.2. Grinding

Ground coffee samples were prepared by grinding 30 g of roasted beans in a Black & Decker SmartGrind Model CBG5 coffee bean grinder (The Black & Decker Corporation, Towson, MD, USA) for 10 s. The tested samples were ground the day of testing and not more than 30 min prior to the evaluation to ensure freshness (Sivetz & Desrosier, 1979)

2.2.3. Brewing

Seven-hundred and twenty milliliters of reverse osmosis, deionized, carbon filtered water was heated to 90 °C and poured over an appropriate amount (35 g) of freshly ground coffee in a Chemex Model CM-6A coffee brewer (Chemex® Corp, Pittsfield, MA, USA). The hot water was poured evenly on the ground coffee through a Chemex® bonded unbleached coffee filter, and 100 mL was immediately poured into each snifter and served to the panelists at approximately 70 °C.

2.3. Descriptive analysis

A panel consisting of six highly trained descriptive members (1 male and 5 females; age range 50-70 years) from the Sensory Analysis Center at Kansas State University evaluated the coffee samples. The panelists had completed 120 h of general training and had a minimum of 1,200 h of general sensory testing including beverages and other food products. Three 90 min orientation sessions were conducted to familiarize the panelists with the evaluation process and the samples to be tested. Three coffee samples from each stage, except for brewed coffee, were

randomly selected to be examined in the first two orientation sessions. The last session was focused on six randomly selected brewed samples. The coffee beans needed for the orientation sessions were roasted 1-2 days prior to the sessions. During orientation, the descriptive panel developed a list of aromatic attributes for the study. A list of 15 appropriate aroma descriptors and their definitions was generated for the samples. The list of descriptors is shown in Table 1. The references needed for each attribute were also determined to calibrate the intensity measurement.

Two replications of each sample were evaluated in this study and were presented monadically and coded with 3-digit random numbers. A total of 30 coffee samples were evaluated for each replication. Coffee samples were placed in a large snifter (414 mL) and covered with a watch glass as a lid. The panelists were instructed to open the watch glass, sniff into the snifter, and then close the lid. They were instructed to sniff the sample as many times as needed. The panelists were provided with a warm wash cloth in a covered Styrofoam cup to breathe-in to cleanse their nasal passages in between each sample. The panelists were given a recuperation time of approximately 3 min between each sample. The panelists assessed six coffee samples per day, resulting in 5 days of testing per replication. The coffee bean samples were roasted 1-2 days prior to the testing of each replication. The aromatic attributes of the samples were identified and the intensities were quantified, utilizing a 0-15 point scale with 0.5 increments (0.0 = none; 0.5 – 5.0 = slight; 5.5 – 10.0 = moderate; 10.5 – 15.0 = extreme).

2.4. Data treatment and analysis

Data were collected using Compusense® Commuter data collection software (version 4.6.702; Compusense Inc., Guelph, Ontario, Canada). The descriptive data were analyzed using analysis of variance (ANOVA) with post-hoc mean separation, using Fisher's least significant

difference. ANOVA was performed using SAS (version 9.1.3; SAS Institute, Cary, NC, U.S.A.) and analyzed at 5% level of significance.

To determine the relationships among degree of roasts, type of coffee beans, and stages of preparation, Principle Component Analysis (PCA) using correlation matrix was performed on all coffee samples, using Unscrambler® (Camo Software A/S, Oslo, Norway). The analyses were performed again among the coffee samples within each preparation stage in order to closely examine the effects of degrees of roasting and coffee varietals in each stage.

3. Results

Among the sensory characteristics identified, floral and fruity notes showed extremely low intensities across all the samples and were removed from the data set. The attribute mean scores for each sample calculated are shown in Table 2.

According to the attribute mean scores table (Table 2), which shows the univariate analysis of data, green coffee beans were generally perceived to be significantly ($P < 0.05$) more beany, musty/earthy, green, and sour than the roasted coffee beans, ground coffee, and brewed coffee. Nutty, sweet aromatic, and pungent were also present in the green coffee beans, however, the intensities were significantly less than the rest of the formats. The only exception was the pungent attribute, which was more intense in the roasted beans and ground coffee, but the intensity decreased significantly in the brewed coffee.

Examining the multivariate relationship between the green coffee bean varieties and the roasted derivatives using principle component analysis, similar to the univariate data, the PCA chart (Fig. 1) showed that all three varieties of green coffee beans were characterized by green, musty/earthy sour aromatics, and beany, attributes. Green and musty/earthy attributes were more prevalent in green coffee beans as compared to the roasted forms. Beany and sour aromatics

were still substantially present even after the coffee beans were roasted, ground, or brewed. Beany seemed to also characterize the brewed coffee. It appeared that brewed coffee samples were distinguished from the roasted and ground forms by the higher intensity of beany attribute as well as the lack of pungent, burnt/acrid, ashy/sooty, roasted, and coffee.

Roasted coffee beans and ground coffee appeared to be clustered closely and possibly separated into two groups by degree of roasting. The first group (Fig. 1) was characterized by pungent, burnt/acrid, ashy/sooty, roasted, and coffee attributes. The members of this group included dark roasted coffee beans, and medium to dark roasted ground coffee. The second group was perceived to be nutty, cocoa, and sweet aromatics and consisted of light roasted coffee beans, and light to medium roasted ground coffee.

3.1. Roasted beans

Table 2 illustrates that coffee, roasted, burnt/acrid, ashy/sooty, sour aromatics, and pungent attributes increased in intensity with the degree of roasting. On the other hand, cocoa and sweet aromatic decreased in intensity in the dark roasted beans. The only one exception was the Hawaii Kona variety, which was perceived to be sweeter as degree of roasting increased. Nutty was scored the highest in the medium roasted beans, and cocoa scored the highest in the medium roast of Ethiopia Kebado beans.

Principle component analysis explained further the multi-dimensional relationship among the roasted coffee beans. In Figure 2, 79 % of the variation in the data were explained by PC1 (63%) and PC2 (16%). The biplot confirmed that burnt/acrid, ashy/sooty, sour aromatics, and pungent were the characteristics of dark roasted beans. Because the dark roasted Hawaii Kona bean was characterized by the sweet aromatic attribute, it was pulled away from the rest of the dark roasted samples towards the middle of the sensory space. Medium roasted beans of Hawaii

Kona and Ethiopia Kebado were perceived to be cocoa, nutty, and sweet, which was in line with the mean table, but also were high in the brown note. The medium roasted El Salvador Bourbon bean sample was placed right in the middle of the sensory space which indicated that aroma attributes perceived from this sample were in harmony with each other, making it complex and more difficult to discern any differences. Lastly, light roasted beans were characterized by beany and green.

3.2. Ground coffee

Similar to the roasted coffee bean, cocoa and sweet aromatics decreased in intensity with degree of roasting in the ground coffee. On the contrary, burnt/acrid, ashy/sooty, sour aromatics, and pungent attributes increased in intensity with the degree of roasting. Most of the aromatic attributes were perceived at higher intensities in the ground coffee compared to the roasted beans, except for sweet aromatic and cocoa.

Figure 3 shows the multivariate relationships among the ground coffee samples, where 88% of the data variations were explained by the first two PC's (64% and 24%, respectively). Going from left to right on PC1, light roasted ground coffee were nutty, cocoa, and sweet aromatics then increasingly became more burnt/acrid, ashy/sooty, sour aromatics, and pungent as the roasting level became darker. Coffee and roasted attributes were most intense in the dark roasted El Salvador Bourbon and the medium roasted Hawaii Kona and Ethiopia Kedado. Dark roasted Ethiopia Kebado was also the perceived to be distinctively musty/earthy.

It was observed here that the dark roasted ground Hawaii Kona, along with the medium roasted ground Ethiopia Kebado and El Salvardor Bourbon were located in the middle of the sensory space, most likely due to the complex aroma profiles each acquired.

3.3. Brewed coffee

Coffee, roasted, burnt/acrid, and ashy/sooty were the attributes that increased with degree of roasting in the brewed coffee, especially in the dark roasted coffee brews (Fig. 4). The first two PC's explained 67% (47% and 20%, respectively) variation in the data. Sweet aromatics attribute was at the highest intensity in the light roasted brewed coffee. Beany attribute decreased in intensity with degree of roasting, while nutty increased in intensity in the medium and dark roasted brews of Ethiopia Kebado and El Salvador Bourbon. The only difference was that nutty attribute was now more intense in the dark roasted brew when it did not come through in the forms of roasted bean and ground coffee, where the light and medium roasts showed more intense nutty attribute.

Distinct differences were observed among the coffee varieties when the brewed samples were evaluated. The samples were not only differed by the degree of roasting but also the coffee origin. Among the light roast brews, El Salvador Bourbon was more cocoa, sweet, and sour aromatics. Ethiopia Kebado was also sweet and sour aromatics, but less cocoa and more beany instead. Hawaii Kona brew, on the contrary, was green, musty/earthy, and lacked sweet, sour, or cocoa. Comparing the medium roast brews, El Salvador Bourbon was more green and musty/earthy, Ethiopia Kebado was burnt/acrid, green, and pungent, and Hawaii Kona was sweet, sour, and cocoa. The dark roast brews were underscored by the characteristics previously mentioned (coffee, roasted, burnt/acrid, ashy/sooty, and nutty).

4. Discussion

Since green coffee beans were perceived to be highly green, musty/earthy, beany, and pungent as compared with the rest of the coffee samples, we focused on the effect of roasting, grinding, and brewing.

Our data show that the roasting of coffee from light to dark resulted in a substantial development of burnt/acrid, pungent, ashy/sooty, and sour notes as well as an increase in the intensity of coffee and roasted attributes. Czerny *et al.* (1999) found that attributes such as roasted, earthy, and smoky increased with degree of roasting. Akiyama *et al.* (2008) reported smoke/roast, phenolic, sweet/caramel, and green to be positively correlated with degree of roasting, while sweet/fruity and acidic attributes to be negatively correlated. Sarrazin *et al.* (2000) reported 'roasted biscuit', 'peanut', 'caramel', 'toasted bread', and 'cereal' to be the sensory notes for light roasted coffee. In our study, we observed that light roast generally yielded sweet, cocoa, and nutty aroma notes while dark roast yielded burnt/acrid, pungent, ashy/sooty, sour, coffee, and roasted aromatics. Green and musty/earthy notes were found to be more prominent in the green coffee bean and were not affected by roast levels. However, it is not to assume that the attributes present in green coffee beans and light roast were absent in the darker roasts. All the aroma notes perceived in green coffee were present at all preparation stages and roast levels. Additional aroma notes were generated during roasting. Some of these compounds became more pronounced with the degree of roasting, while others decreased in intensity. The intense aroma characters formed during roasting may have masked the less potent notes, making it difficult to detect or discern any differences (Grosch, 2001; Laing, 2004).

Most of the aromatic attributes were perceived at higher intensities in the ground coffee stage, as expected because grinding exposes the developed aroma compounds that are nested inside of the roasted coffee beans. However, some attributes that were significantly different ($P < 0.05$) in the whole roasted bean samples were no longer different (e.g. sweet aromatics). Again, this probably was because other aromatic compounds were present at high concentrations in the ground coffee, which consequently made it difficult to detect small differences in a single

attribute that did not have high enough intensity. This phenomenon can be explained by a theory proposed by Laing (2004) who suggested that humans can only discriminate up to a certain number of odorants in an aroma mixture. Aromatic compounds must compete for receptor sites; therefore the more abundant odorants have higher chances to seize the receptor sites. Consequently, the stimulation caused by the less abundant compounds in the mixture is reduced.

Laing (2004) also explained that the greater number of odorants in the mixture more the chance of overlapping of response patterns. Grosch (2001) supported this theory and clarified further that the odorants with higher intensities could mask or suppress the less intense aroma notes. Combining Grosch's theory with the theory proposed by Laing (2004), we can explain the complexity of the aroma profiles of medium roasted ground coffee samples (Ethiopia Kebado and El Salvador Bourbon) and the dark roasted ground Hawaii Kona coffee, as seen in Figure 3. It was difficult to identify the differences of aroma profiles among the three coffee varieties at medium roast (or dark roast, in the case of Hawaii Kona) due to the high intensity of odorants produced by the roast level and format of coffee (ground). At this point it is known that grinding is the stage where the developed aromatic compounds are most exposed to the environment and generally medium roast is where most odorants are fully developed and concentrated (Illy & Viani, 2005; Sivetz & Desrosier, 1979; Yeretzian *et al.*, 2002).

At the brew stage, the intensities of the aroma decreased. The process of brewing involves extracting aromatic oils and flavor compounds from ground coffee by means of hot water, resulting in weaker concentrations of aromatic compounds in brewed coffee (Illy & Viani, 2005; Sivetz & Desrosier, 1979; Yeretzian *et al.*, 2002). Sweet aromatic was perceived to be more intense in the light roasted brew. Because the aromas are more diluted, it was easier to differentiate between coffee varieties and roast levels, as well as to predict the roast level that

might be optimal for each variety. El Salvador Bourbon was perceived to be sweet, sour, and cocoa in the light roasted brew, became highly green, musty/earthy, and pungent in the medium roasted brew, and finally developed roasted, coffee, ashy/sooty, and nutty notes in the dark roasted brew. It appeared that the aroma profile of medium roast may not be the optimum level for the El Salvador Bourbon brew. Ethiopia Kebado coffee brew had similar aroma profiles. It was sweet, but beany and musty/earthy in the light roasted brew, also became highly pungent and burnt/acrid in the medium roasted brew, and formed roasted, coffee, ashy/sooty, and nutty in the dark roasted brew. The optimum roast level for Ethiopia Kebado brew may be the dark roast. Brewed Hawaii Kona coffee was green, musty/earthy, and pungent in the light roast, started to build the sweet, sour, and cocoa notes in the medium roast, and became nutty, burnt/acrid, ashy/sooty, roasted, and coffee in the dark roasted brew. The optimal roast level for Hawaii Kona coffee was likely the medium roast.

It was also possible to assess the optimal roast level for the stages of roasted beans. The medium roast appeared to be the optimal roast level for all varieties, yielding the most complex aroma attributes (El Salvador Bourbon) or achieving distinctive sweet, brown, nutty, and cocoa aromas as in Hawaii Kona and Ethiopia Kebado. Hawaii Kona beans may also be appropriate to be dark roasted as well, since it became distinctively sweet, while also developed the burnt/acrid, coffee, and roasted notes. Consumer acceptability data would be required for proper optimization of the roast levels.

5. Conclusions

The result of this study indicated that aroma characters of coffee detected by the descriptive panel were mainly affected by the stage of preparation, and also by degrees of roasting because of the formation of aroma compounds. Grinding increased the surface area and

released aroma volatiles, hence had more intense characteristics as compared to whole roasted beans and brewed coffee. Brew coffee was the stage where the different aroma profiles of the coffee origins were easiest to discern, due to the lower concentration of aromatic compounds. This was not the case in roasted beans or ground coffee because of the complexity of the aroma mixture in these two stages. In general, light roast yielded sweet, cocoa, and nutty aromas. The Hawaii Kona variety, however, was sweeter in aroma in the dark roast. Medium roast yielded complex aroma profiles and is possibly the optimal roast level for most samples. Dark roast is characterized by burnt/acrid, ashy/sooty, sour, pungent, coffee, and roasted aromas. Our study showed that there is evolution and change in the aroma characteristics from green beans to brewed coffee. Aroma characters of coffee detected by human are mainly affected by the stage of preparation and degrees of roast and less by the origin of coffee bean. However, the origin of the coffee impacts how the intensity these aroma notes are affected by the roast level.

In the future, the flavor profiles of the brewed coffee could be examined to understand how the changes in aroma in each form of coffee and degree of roasting affect the perceived flavor characteristics of the brewed coffee. Consumer evaluations would be necessary to identify the key attributes that might impact acceptability.

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Table 1.
Aromatic descriptors used for the evaluation of green coffee beans, roasted coffee beans, ground coffee, and brewed coffee

Descriptors	Definition	References
Coffee	A distinctly roasted brown, slightly bitter aromatic characteristic of brewed coffee. Additional descriptors may/may not include woody, oily, acidic, and full bodied and these notes may occur at varying intensities	Folgers Classic Roast Ground Coffee = 6.0
Roasted	Dark brown impression characteristic of products cooked to a high temperature; does not include bitter or burnt notes	Folgers Classic Roast Ground Coffee = 6.0
Burnt/Acrid	The somewhat sharp, acrid notes associated with a dark brown impression of an over-cooked, almost scorched product	Folgers Classic Roast Ground Coffee = 2.0 Sethness AP100 Caramel Color = 5.0 (aroma) Starbucks Espresso Ground Coffee = 8.0 (aroma)
Brown	Full, round, aromatic impression always characterized as some degree of darkness, generally associated with other attributes (i.e. tasted, nutty, sweet, etc.)	Sethness AP100 Caramel Color = 3.5 (aroma) Bush's Best Pinto Beans (Canned) = 5.0 (aroma) C&H Brown Sugar in Water = 5.0 (aroma)
Beany	The brown, somewhat musty, earthy aromatics associated with cooked legumes such as pinto beans and lima beans	Kroger's Frozen Baby Lima Beans = 6.0 (aroma) Bush's Best Pinto Beans (Canned) = 7.0 (aroma)
Nutty	A light, brown, slightly musty aromatic associated with nuts, wheat germ, certain whole grains, and dry grain stems	Kretschmer Wheat Germ = 3.0 (aroma)
Cocoa	Brown, sweet, dusty often bitter aromatics associated with cocoa beans and powdered cocoa	Hershey's Cocoa Powder in Water = 7.5 (aroma)
Musty/Earthy	Humus-like aromatics that may or may not include soil, decaying vegetation, or cellar like characteristics	Bush's Best Pinto Beans (Canned) = 5.0 (aroma) Kroger's Frozen Baby Lima Beans = 5.0 (aroma)
Floral	Sweet, light, slightly perfumy impression associated with flowers	Diluted Welch's White Grape Juice = 5.0 (aroma)
Fruity	A sweet, floral aromatic blend of a variety of ripe fruits excluding citrus	Diluted Welch's White Grape Juice = 4.5 (aroma)
Green	Aromatics associated with fresh green peapods. May include beany, increased pungent, musty/earthy, bitter, and astringent	Kroger Frozen Lima Beans = 9.0 (aroma)
Ashy/Sooty	Bark-like lingering aromatics associated with a cold campfire	Benzyl Disulfide = 4.0 (aroma)
Sweet Aromatic	An aromatic associated with the impression of sweet products	C&H Brown Sugar in Water = 3.0 (aroma)
Sour Aromatic	An aromatic associated with the impression of a sour product	Bush's Pinto Bean (Canned) = 2.0 (aroma) Diluted Heinz Distilled White Vinegar = 3.0 (aroma)
Pungent	A sharp physically penetrating sensation in the nasal cavity	Diluted Heinz Distilled White Vinegar = 2.0 (aroma)

Table 2

Effect of coffee varieties, stages/steps of preparation, and degrees of roast on the aromatic sensory attributes (mean scores of 2 replicates) of the coffee samples.

		Stages/steps									
		Green	Roast			Ground			Brew		
Attributes*	**Coffee Varieties**		**Light**	**Medium**	**Dark**	**Light**	**Medium**	**Dark**	**Light**	**Medium**	**Dark**
Coffee	El Salvador Bourbon	0.00^{g}	9.90^{d}	10.80^{cd}	11.40^{bc}	11.60^{abc}	12.10^{ab}	12.50^{a}	3.90^{f}	4.50^{ef}	4.90^{e}
	Ethiopia Kebado	0.00^{d}	10.00^{b}	10.70^{ab}	11.30^{ab}	10.80^{ab}	11.80^{a}	11.50^{a}	4.00^{c}	4.60^{c}	5.40^{c}
	Hawaii Kona	0.00^{f}	9.50^{d}	10.90^{bc}	11.50^{abc}	10.50^{cd}	12.40^{a}	12.00^{ab}	4.30^{e}	4.70^{e}	5.00^{e}
Roasted	El Salvador Bourbon	0.00^{g}	8.54^{d}	9.38^{cd}	10.04^{bc}	10.21^{bc}	10.75^{ab}	11.38^{a}	3.17^{f}	3.75^{ef}	4.42^{e}
	Ethiopia Kebado	0.00^{e}	8.63^{c}	9.08^{bc}	9.67^{abc}	9.38^{bc}	10.83^{a}	10.42^{ab}	3.17^{d}	3.75^{d}	4.46^{d}
	Hawaii Kona	0.00^{f}	8.38^{d}	9.42^{cd}	9.75^{bc}	9.75^{bc}	11.08^{a}	10.67^{ab}	3.75^{e}	3.79^{e}	4.04^{e}
Burnt/Acrid	El Salvador Bourbon	0.00^{e}	2.21^{bcd}	2.33^{bcd}	3.17^{b}	3.00^{bc}	3.13^{b}	4.25^{a}	1.42^{d}	1.92^{d}	2.08^{cd}
	Ethiopia Kebado	0.00^{d}	1.79^{c}	2.00^{c}	3.54^{b}	2.25^{c}	3.21^{b}	4.46^{a}	1.54^{c}	1.75^{c}	1.79^{c}
	Hawaii Kona	0.00^{d}	1.83^{c}	2.17^{bc}	2.83^{ab}	2.13^{bc}	3.58^{a}	3.50^{a}	1.71^{c}	1.71^{c}	1.96^{bc}
Brown	El Salvador Bourbon	0.08^{d}	6.75^{ab}	6.50^{ab}	6.29^{b}	6.54^{ab}	7.17^{a}	7.08^{a}	3.83^{c}	3.42^{c}	3.92^{c}
	Ethiopia Kebado	0.42^{c}	6.75^{a}	7.04^{a}	6.33^{a}	6.58^{a}	7.13^{a}	6.71^{a}	3.67^{b}	3.42^{b}	3.92^{b}
	Hawaii Kona	0.00^{c}	6.46^{a}	7.13^{a}	6.67^{a}	6.75^{a}	7.17^{a}	7.08^{a}	3.38^{b}	3.83^{b}	3.75^{b}
Beany	El Salvador Bourbon	3.79^{a}	1.88^{cde}	1.63^{de}	1.33^{e}	1.46^{de}	1.67^{de}	1.21^{e}	2.67^{bc}	2.75^{b}	2.25^{bcd}
	Ethiopia Kebado	3.42^{a}	1.63^{b}	1.58^{b}	1.50^{b}	1.83^{b}	1.67^{b}	2.13^{b}	3.04^{a}	2.13^{b}	2.08^{b}
	Hawaii Kona	3.71^{a}	1.71^{cde}	1.71^{cde}	1.50^{de}	1.71^{cde}	1.38^{e}	1.58^{cde}	2.38^{bc}	2.71^{b}	2.25^{bcd}
Nutty	El Salvador Bourbon	0.88^{d}	2.00^{abc}	2.08^{ab}	1.75^{abc}	2.33^{a}	2.25^{ab}	1.88^{abc}	1.46^{cd}	1.71^{bc}	1.75^{abc}
	Ethiopia Kebado	0.92^{d}	2.25^{abc}	2.54^{a}	1.67^{bcd}	2.33^{ab}	2.08^{abc}	2.13^{abc}	1.46^{cd}	1.46^{cd}	1.88^{bcd}
	Hawaii Kona	1.00^{d}	2.13^{abc}	2.29^{ab}	1.96^{abc}	2.54^{a}	2.17^{ab}	2.42^{a}	1.63^{bcd}	1.58^{cd}	1.50^{cd}

Table 2 (Continued)

		Stages/steps								
		Green	Roast			Ground			Brew		
Attributes*	**Coffee Varieties**		**Light**	**Medium**	**Dark**	**Light**	**Medium**	**Dark**	**Light**	**Medium**	**Dark**
Cocoa	El Salvador Bourbon	0.00^{d}	1.79^{a}	1.75^{a}	1.08^{abc}	1.54^{ab}	1.58^{ab}	1.25^{abc}	0.88^{bc}	0.42^{cd}	0.75^{bcd}
	Ethiopia Kebado	0.00^{e}	2.42^{ab}	2.79^{a}	1.29^{bcd}	2.21^{abc}	1.38^{bcd}	1.04^{cde}	0.46^{de}	0.42^{de}	0.54^{de}
	Hawaii Kona	0.00^{d}	2.08^{a}	1.92^{a}	1.63^{ab}	2.33^{a}	1.71^{a}	1.29^{abc}	0.58^{bcd}	0.50^{cd}	0.25^{cd}
Musty/ Earthy	El Salvador Bourbon	5.25^{a}	2.13^{b}	2.21^{b}	2.38^{b}	2.58^{b}	2.50^{b}	2.58^{b}	2.50^{b}	2.63^{b}	2.29^{b}
	Ethiopia Kebado	4.54^{a}	2.25^{b}	2.21^{b}	2.67^{b}	2.38^{b}	2.63^{b}	3.88^{a}	2.25^{b}	2.29^{b}	2.33^{b}
	Hawaii Kona	5.54^{a}	2.79^{b}	2.25^{b}	2.46^{b}	2.25^{b}	2.71^{b}	2.71^{b}	2.38^{b}	2.21^{b}	2.21^{b}
Green	El Salvador Bourbon	4.13^{a}	0.38^{c}	0.08^{c}	0.00^{c}	0.42^{c}	0.58^{bc}	0.17^{c}	0.38^{c}	1.08^{b}	0.58^{bc}
	Ethiopia Kebado	3.83^{a}	0.17^{b}	0.25^{b}	0.08^{b}	0.71^{b}	0.33^{b}	0.75^{b}	0.67^{b}	0.67^{b}	0.71^{b}
	Hawaii Kona	4.17^{a}	0.33^{b}	0.25^{b}	0.29^{b}	0.54^{b}	0.21^{b}	0.50^{b}	0.75^{b}	0.67^{b}	0.63^{b}
Ashy/ Sooty	El Salvador Bourbon	0.00^{e}	2.13^{bc}	2.58^{b}	3.58^{a}	2.38^{b}	2.54^{b}	3.50^{a}	1.07^{d}	1.29^{cd}	1.42^{cd}
	Ethiopia Kebado	0.00^{e}	1.75^{bcd}	2.00^{bc}	3.33^{a}	2.08^{b}	2.17^{b}	3.33^{a}	1.21^{d}	1.50^{cd}	1.75^{bcd}
	Hawaii Kona	0.00^{f}	2.46^{abc}	2.17^{bcd}	2.71^{ab}	1.88^{cd}	2.92^{a}	2.38^{abc}	1.21^{e}	0.96^{e}	1.58^{de}
Sweet Aromatic	El Salvador Bourbon	0.96^{d}	2.21^{ab}	2.04^{abc}	1.71^{bc}	2.42^{a}	2.04^{abc}	1.63^{bc}	1.88^{abc}	1.58^{c}	1.54^{cd}
	Ethiopia Kebado	1.04^{d}	2.67^{a}	2.63^{a}	1.79^{abcd}	2.50^{ab}	2.13^{abc}	1.50^{cd}	1.71^{bcd}	1.46^{cd}	1.58^{cd}
	Hawaii Kona	1.00^{d}	2.04^{abcd}	2.49^{abc}	2.96^{a}	2.79^{ab}	2.00^{abcd}	2.13^{abcd}	1.58^{bcd}	1.50^{cd}	1.50^{cd}
Sour Aromatic	El Salvador Bourbon	2.33^{a}	1.58^{b}	1.54^{b}	2.00^{ab}	1.50^{b}	1.83^{ab}	2.08^{ab}	1.75^{ab}	1.58^{b}	1.71^{ab}
	Ethiopia Kebado	2.33^{ab}	1.38^{d}	1.42^{cd}	1.92^{bcd}	1.50^{cd}	$1.92b^{cd}$	2.38^{a}	1.96^{abc}	1.54^{cd}	1.63^{cd}
	Hawaii Kona	2.33^{a}	1.71^{ab}	1.50^{ab}	2.33^{a}	1.25^{b}	1.88^{ab}	1.88^{ab}	1.50^{ab}	1.83^{ab}	1.38^{ab}
Pungent	El Salvador Bourbon	1.29^{de}	1.33^{cd}	1.54^{cd}	2.25^{ab}	2.00^{bc}	2.04^{bc}	2.75^{a}	0.50^{f}	0.83^{ef}	0.79^{ef}
	Ethiopia Kebado	1.08^{cde}	1.33^{cd}	1.58^{bc}	2.00^{b}	1.42^{c}	2.04^{b}	2.88^{a}	0.67^{e}	0.79^{e}	0.83^{de}
	Hawaii Kona	1.25^{bc}	1.42^{bc}	1.50^{abc}	1.83^{ab}	1.33^{bc}	2.33^{a}	2.08^{ab}	0.88^{c}	0.75^{c}	0.71^{c}

^{abcdefg}Means within each row with different letters are significantly different ($P < 0.05$)

*A 0-15 (0 = none and 15 = extreme) point scale with 0.5 point increments was used by the descriptive panel to measure the aroma intensities

Fig. 1. PCA chart depicting relationships among the samples (◆; green coffee beans, roasted coffee beans, ground coffee, and brewed coffee) and the descriptive aroma attributes (▲).

Fig. 2. PCA chart depicting relationships among the roasted coffee bean samples (◆) and the descriptive aroma attributes (▲).

Fig. 3. PCA chart depicting relationships among the ground coffee samples (◆) and the descriptive aroma attributes (▲).

Fig. 4. PCA chart depicting relationships among the brewed coffee samples (◆) and the descriptive aroma attributes (▲).

Legend for the figures

Coffee samples: BB – Green El Salvador Bourbon coffee; ET – Ethiopia Kebado coffee; KN – Hawaii Kona coffee.

Roasting: L – Light roast; M – Medium roast; D – Dark roast

Stages/steps: RAW – Green beans; RST – Roasted beans; GRD – Ground coffee; BRW – Brewed coffee

Fig. 1.

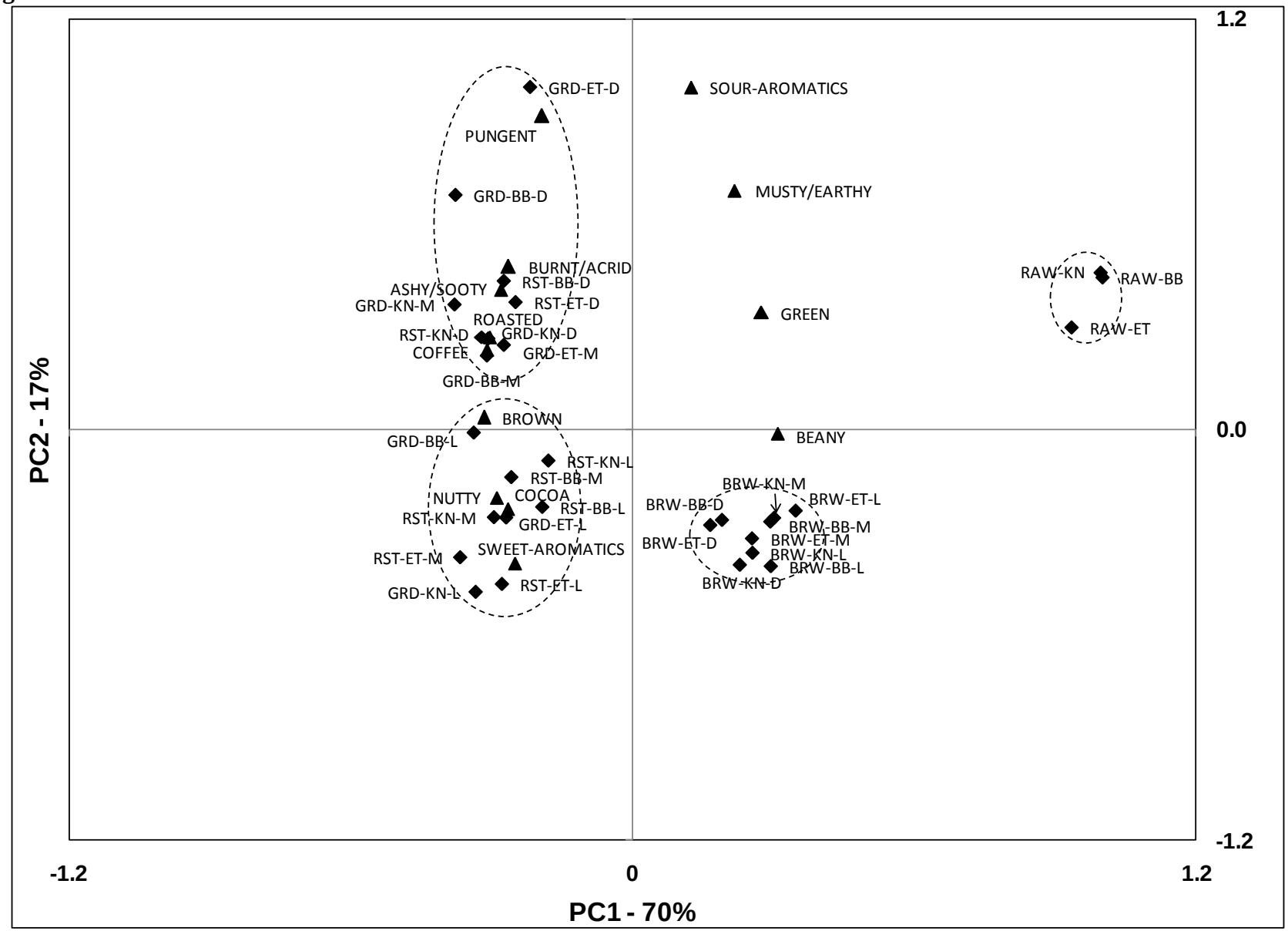

GRD-ET-D
PUNGENT
GRD-BB-D
BURNT/ACRID
RST-BB-D
ASHY/SOOTY
GRD-KN-M
RST-ET-D
ROASTED
RST-KN-D
GRD-KN-D
COFFEE
GRD-ET-M
GRD-BB-M
BROWN
GRD-BB-L
RST-KN-L
RST-BB-M
NUTTY
COCOA
RST-BB-L
RST-KN-M
GRD-ET-L
RST-ET-M
SWEET-AROMATICS
GRD-KN-L
RST-ET-L
SOUR-AROMATICS
MUSTY/EARTHY
GREEN
BEANY
BRW-KN-M
BRW-ET-L
BRW-BB-D
BRW-BB-M
BRW-ET-D
BRW-ET-M
BRW-KN-L
BRW-BB-L
BRW-KN-D
RAW-KN
RAW-BB
RAW-ET
1.2
0.0
-1.2
-1.2
0
1.2
PC2 - 17%
PC1 - 70%

Fig. 2.

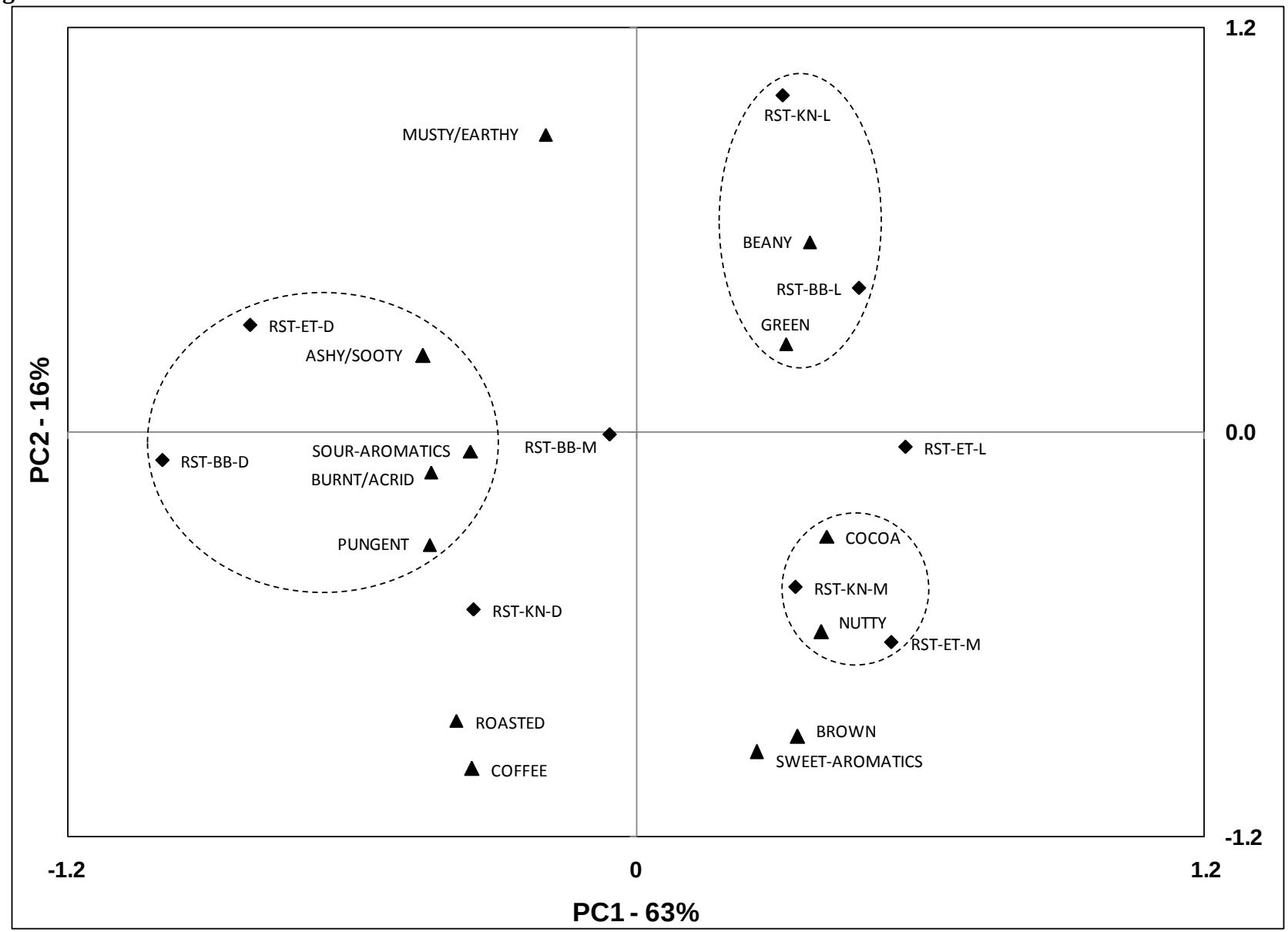

1.2
0.0
-1.2
-1.2
0
1.2
PC2 - 16%
PC1 - 63%
MUSTY/EARTHY
RST-KN-L
BEANY
RST-BB-L
GREEN
RST-ET-D
ASHY/SOOTY
RST-BB-M
RST-ET-L
SOUR-AROMATICS
RST-BB-D
BURNT/ACRID
PUNGENT
COCOA
RST-KN-M
NUTTY
RST-ET-M
RST-KN-D
ROASTED
BROWN
SWEET-AROMATICS
COFFEE

Fig. 3.

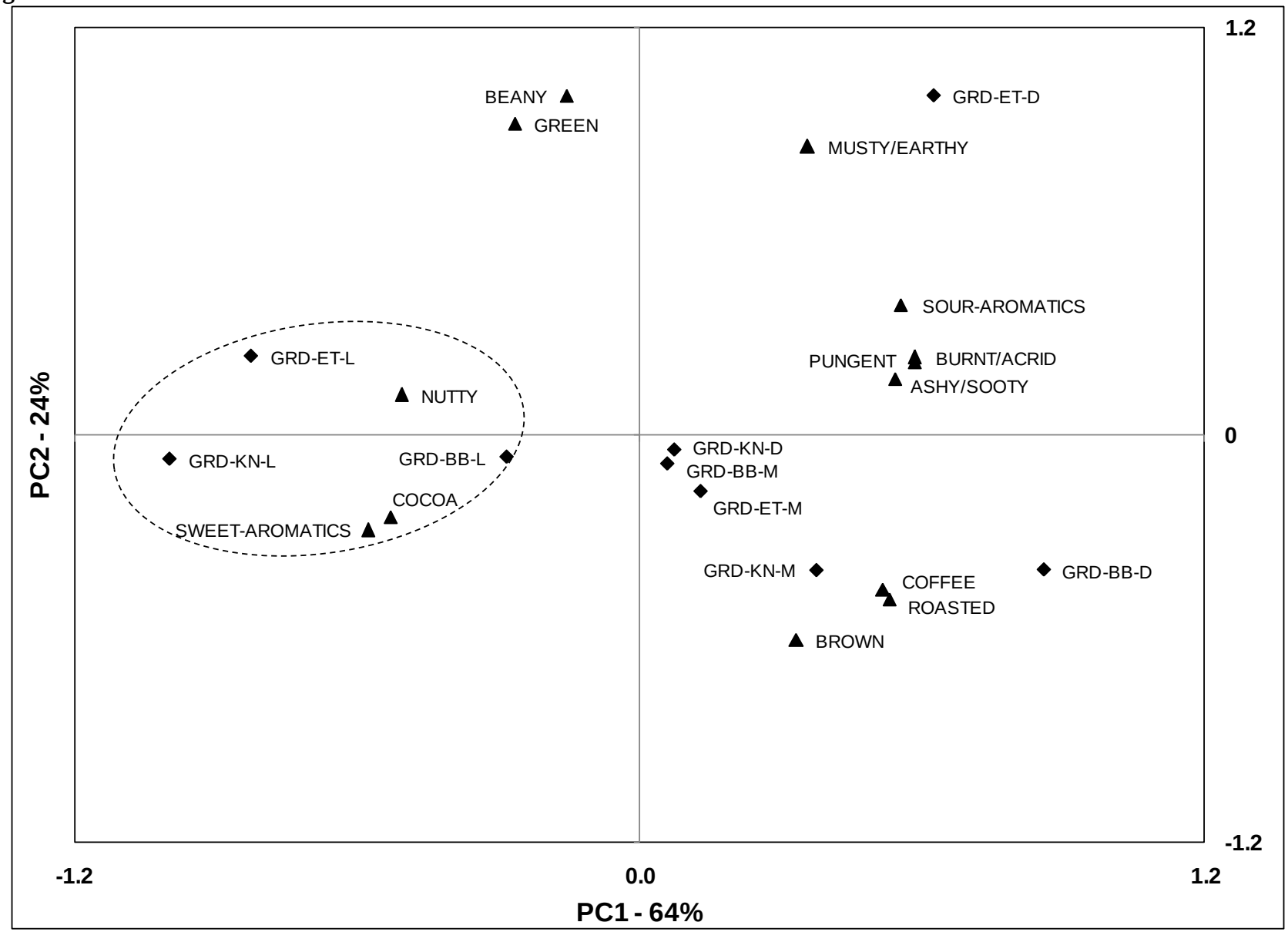
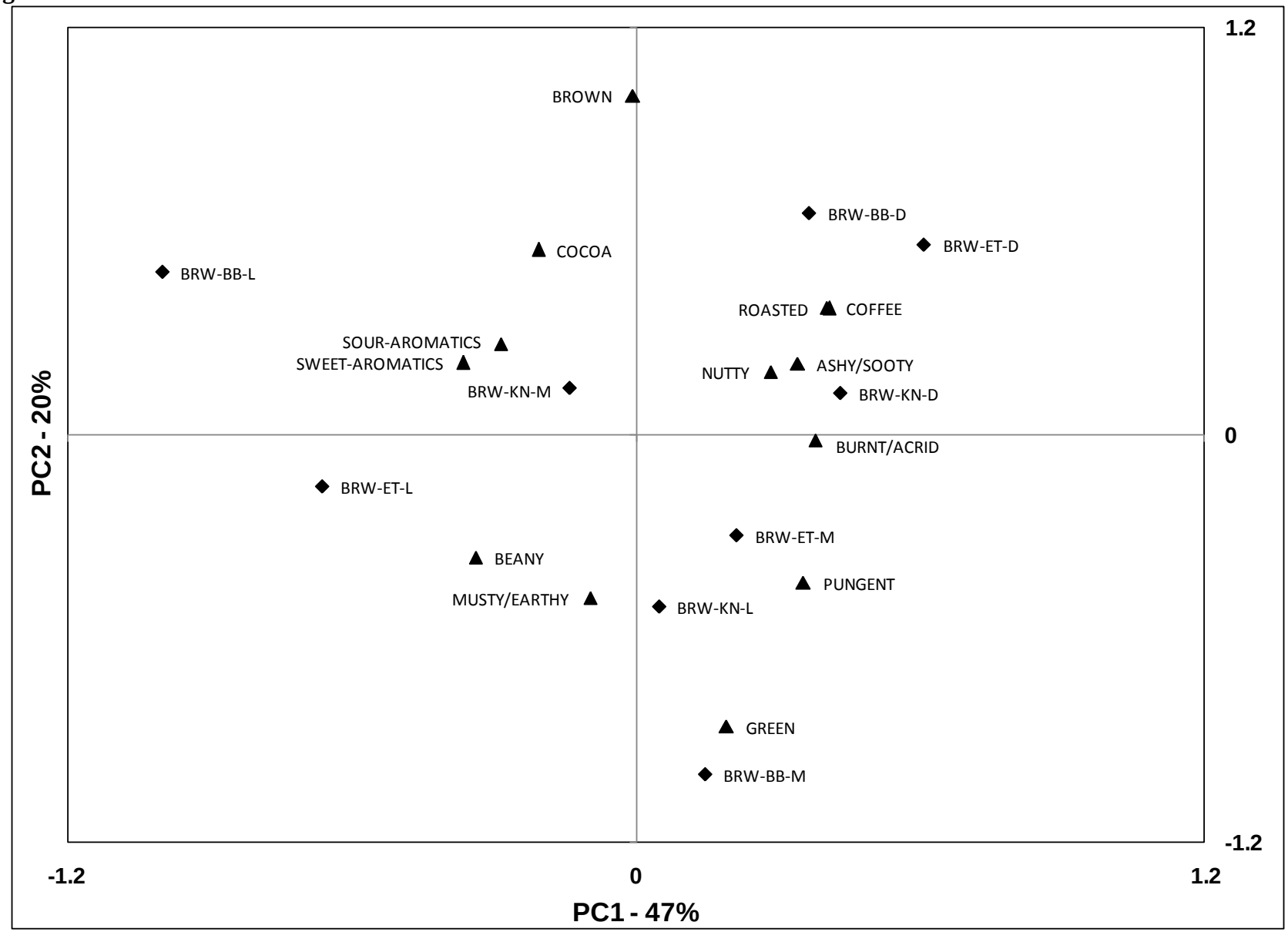

1.2
0
-1.2
-1.2
0.0
1.2
PC2 - 24%
PC1 - 64%
BEANY
GREEN
GRD-ET-D
MUSTY/EARTHY
SOUR-AROMATICS
PUNGENT
BURNT/ACRID
ASHY/SOOTY
GRD-ET-L
NUTTY
GRD-KN-L
GRD-BB-L
COCOA
SWEET-AROMATICS
GRD-KN-D
GRD-BB-M
GRD-ET-M
GRD-KN-M
COFFEE
ROASTED
GRD-BB-D
BROWN

Fig. 4.


BROWN
BRW-BB-D
BRW-ET-D
COCOA
BRW-BB-L
ROASTED COFFEE
SOUR-AROMATICS
SWEET-AROMATICS
NUTTY
ASHY/SOOTY
BRW-KN-M
BRW-KN-D
BURNT/ACRID
BRW-ET-L
BRW-ET-M
BEANY
PUNGENT
MUSTY/EARTHY
BRW-KN-L
GREEN
BRW-BB-M
1.2
0
-1.2
-1.2
0
1.2
PC2 - 20%
PC1 - 47%