

**Determining the impact of roasting degree, coffee to water ratio and brewing method on  
the sensory characteristics of cold brew Ugandan coffee**

by

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## **Abstract**

The sensory characteristics of brewed coffee are dependent on a number of factors such as origin and species variety of the roasted coffee beans, roasting degree, grind level of bean, coffee to water ratio, brew water hardness and temperature, length of contact time and level of agitation during extraction process and the type of filter material. Cold brewing of coffee has become more popular today. The demand for cold brew coffee in the market can be attributed to its distinctive sensory characteristics. However, there exists little-published research on the factors that impact the sensory characteristics of cold brew coffee. The objectives of this study were to determine the impact of a) degree of roasting, b) coffee to water ratio (C2WR) and c) brewing methods on cold brew coffee from d) Ugandan coffee beans. Four distinct coffee samples, sourced from different lowland and mountainous regions in Uganda, were roasted and tested using a factorial design that allowed comparison of all main factors (a-d) and their interactions. The samples were evaluated by a highly trained sensory panel based on 42 attributes from a previously published coffee lexicon. Results showed that all aspects studied (Ugandan variety, roast degree, C2WR, and brewing method) had an impact on most of the attributes. For example, Robusta coffees generally were bitterer than Arabica coffees and the Dark roast samples generally had more bitterness than the Medium roast coffees. Coffee samples that were brewed using a high coffee to water ratio (C2WR) generally were more bitter than the coffees that were brewed using a low C2WR. However, although most of the main effects had a significant impact, their effects were mitigated by their interaction with other factors. For example, when Medium-roast Robusta coffee was slow-dripped with a higher C2WR, it was more bitter than the corresponding Arabica samples, but this Arabica and Robusta, when steeped, had similar intensities for the bitter taste. Thus, although major impacts are critical, individual sample combinations must be considered when evaluating brewed coffee samples for the impact on the sensory characteristics.

This study is relevant for sensory professionals and persons in the industry such as roasters, baristas, and product developers.

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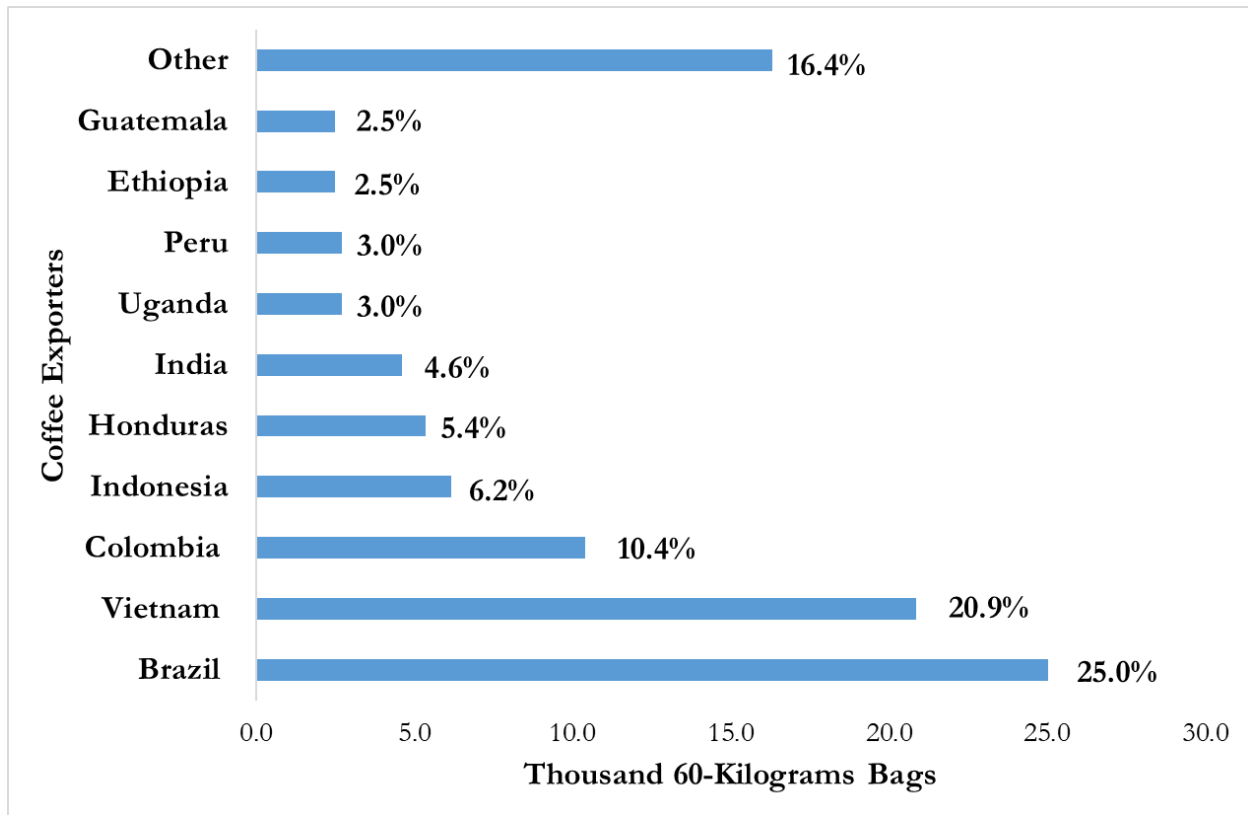
I am thankful to all the graduate students at the center and the panelists without whom I would not have been able to accomplish this.

This one is for you Suzan!

# Chapter 1 - Literature Review

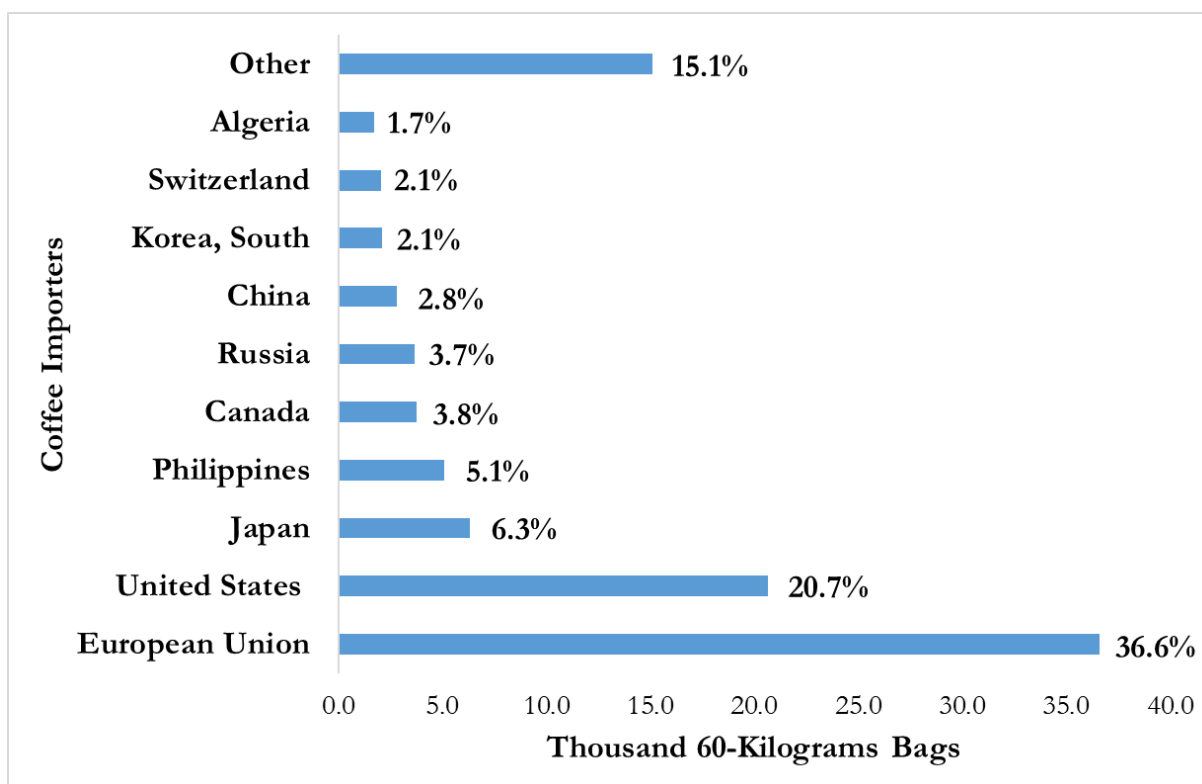
## World coffee production and marketing

Coffee is the second most traded commodity by value globally after oil. In the coffee year 2016/17, global coffee production was 160.5 million 60-kg bags and the total exports were 112.4 million 60-kg bags (USDA, 2017). Coffee contributes significantly to the foreign exchange income of a number of countries in Latin America, Africa, and Asia. Figure 1-1 shows the world's largest coffee exporters for the coffee year 2016/17.



**Figure 1-1 World Total Exports in the coffee year 2016/17**

Source: (USDA, 2017)



**Figure 1-2 World Total Imports in the coffee year 2016/17**

Source: (USDA, 2017)

Coffee is also one of the most popular beverages in the world with an estimated more than 400 billion cups being consumed per year (Sylwia Chudy, 2014; National Coffee Association, 2018).

The United States Department of Agriculture reported that in the coffee year 2016/17, the European Union imported 36.6% of the world coffee, followed by the United States which imported 20.7% as seen in Figure 1-2.

The coffee tree belongs to the genus *Coffea* in the Rubiaceae family. *Coffea arabica* (Arabica) and *Coffea canephora* (Robusta) are the two species out of over 80 coffee species that are of economic significance. Arabica coffee accounts for approximately 60-70% of the global production and Robusta is responsible for the rest (International Trade Centre, 2011; Farah, 2012). Robusta varies from Arabica in the required growing climate, physical features, and chemical composition. Robusta coffee is usually grown in the low altitude areas and has a higher resistance to pests and diseases while Arabica coffee is usually grown in higher altitude areas and is more competitive on the international market due to its superior quality (International Trade Centre, 2011). Robusta green beans contain higher levels of antioxidant compounds, caffeine and chlorogenic acids,

polysaccharides, soluble solids and have more proteins in forms of peptides and amino acids as compared to the Arabica green beans (Farah, 2012). Arabica green beans, on the other hand, are higher in sucrose and have higher levels of trigonelline as compared to the Robusta green beans (Adriana, 2009; Farah, 2012).

**Table 1-1 Key average chemical concentrations for green Arabica and Robusta coffee beans**

<b>Compounds</b>	<b>Concentration(g/100 g)</b>	
	<b>Arabica</b>	<b>Robusta</b>
Caffeine	0.9-1.3	1.5-2.5
Carbohydrates/fiber		
Sucrose	6.0-9.0	0.9-4.0
Reducing sugars	0.1	0.4
Polysaccharides	34-44	48-55
Chlorogenic acids	4.1-7.9	6.1-11.3
Minerals	3.0-4.2	4.4-4.5
Protein/peptides	10.0-11.0	11.0-15.0
Free amino acids	0.5	0.8-1.0
Trigonelline	0.6-2.0	0.6-0.7
Coffee oil	15-17.0	7.0-10.0
Diterpenes	0.5-1.2	0.2-0.8

Source: (Farah, 2012)

### **Uganda coffee production and marketing**

Uganda's coffee production comprises a wide array of wet processed, dry processed, shade-grown (agro-forested), mountainous and equatorial Robusta and Arabica coffees. Coffee remains Uganda's top export with bean exports in coffee production year 2016/2017 averaging at four million 60-kg bags. Robusta coffee constitutes about 80% of the total coffee exports (USDA, 2017). In Uganda, coffee exports continue to contribute immensely to the country's foreign exchange earnings and also account for a significant proportion of its gross domestic product (GDP).

Over 95% of Uganda's coffee is exported as green beans through direct sales to buyers mainly in the European Union, North America, and Asia. The value of Uganda's coffee has however dropped considerably over the years mainly due to unsustainable and limited competitiveness at the International market (Kufa et al., 2011). Uganda's low domestic coffee consumption can be explained by the limited competitiveness with respect to the imported value-added coffees that are

more expensive among other reasons. This has made the campaigns to promote domestic consumption less cost-effective and unreliable(Baffes, 2006).

## **Coffee processing**

The ripening of the coffee cherries occurs either evenly or unevenly and this influences the method of picking that is used by the farmers. There are two methods of harvesting coffee: selective harvesting and strip harvesting. With selective harvesting, picking is done by hand as only the red, ripe cherries are selected. This results in a lower percentage of unripe cherries in the harvested coffee and higher costs to the producers. Strip harvesting is done either manually or mechanically. This method is characterized by harvested lots of varying maturation levels and lower coffee quality (Odello, 2001)

The harvested coffee cherries are processed to extract the beans. This primary processing can either be a dry process or a wet process.

### **Primary processing**

#### **Dry processing**

The dry process results in “natural coffees” while the wet process produces the “washed coffees”. The dry process involves the separation of the extraneous matter such as the twigs and leaves from the cherries especially in cases if strip harvesting is done. This is usually done by immersing the cherries in running water. The coffee is dried on large patios made of cement and is turned over every 30-40 minutes to allow every cherry to be exposed to the sun and is covered with plastic if it rains so that no water is absorbed. The coffee cherries are dried from approximately 60% moisture content to 15% and then transferred to mechanical dryers until the coffee reaches 11-13% moisture content. The dried cherries are then hulled to release the green beans (International Trade Centre, 2011; Farah, 2012).

#### **Wet processing**

After harvesting less dense coffee cherries are removed by a floatation process using a washer separator which also washes the cherries. The clean cherries undergo a pulping process in which the wet beans are squeezed out from the cherries leaving the pulp. The wet parchment beans have a mucilage layer around them that is removed by biochemical enzyme activity through controlled

fermentation to give ‘fully washed’ coffees. The wet parchment free of mucilage at moisture contents of 50 – 60 % is then dried on suitable raised drying mesh to the required 13 % moisture content. Mechanical driers to hasten the drying regime can be used after draining off most of the water. In the case that the mucilage is mechanically removed the coffees produced are referred to as semi-washed. Drying coffee solely on patios takes 6-7 days for washed coffees, 8-9 days for pulped naturals (semi-washed), and 12-14 days for natural (dry-processed) coffees. Coffee beans are typically dried on a patio until they reach a moisture content of 15% and are then transferred to mechanical dryers (Odello, 2001; Farah, 2012).

### **Secondary Processing**

Secondary processing transforms the clean coffee into the various coffee grades that meet the international standards. The process involves cleaning the coffee followed by size grading using perforated screens of the desired size. The sorted beans are gravimetrically sorted to have uniform specific density before bagging off in jute bags of 60 Kg.

### **Tertiary processing**

With tertiary processing, the value is added to the processed raw coffee mainly by roasting. The roasted beans are either consumed at this stage or are used as raw materials for the production of soluble coffees such as the freeze-dried and spray-dried coffees. Alternatively, processed green beans undergo a process of decaffeination. The decaffeination process can also be applied to both roasted beans and soluble coffees. (International Trade Centre, 2011)

### **Coffee roasting process**

The process of coffee roasting is described by the degree of roasting and this takes account of physical and chemical properties of the coffee beans. These changes include a change in outer color of the beans, increase in brittleness and reduction in weight of the beans, and changes in the chemical composition as a result of pyrolysis, caramelization, Strecker, and Maillard reactions (Baggenstoss et al., 2008; Bekedam et al., 2008; Moon et al., 2009; Farah, 2012; Ruosi et al., 2012; Rufián-Henares, José A. A., 2014; Dulsat-Serra et al., 2016; Gabriel-Guzmán et al., 2017). It is through the roasting process that coffee beans gain their aroma and flavor. These properties are influenced by temperature and time conditions within the beans. According to Baggenstoss et al., (2008), heat transfer occurs by contact, conduction, radiation, and convection but convection is faster and the most effective for uniform roasting. This explains the industry’s

preference of the fluid bed roasters which have the coffee beans in contact with the hot air to the common drum roaster in which the beans are in contact with a hot surface(Farah, 2012; Ruosi et al., 2012; Gabriel-Guzmán et al., 2017)

The color of the coffee bean or ground coffee is commonly used to describe the degree of roast. Basing on the temperature measurements, the intensity of the bean color is correlated to their final roasting temperature(Baggenstoss et al., 2008; Dmowski, P., & Dąbrowska, 2014)

In 1995, the Specialty Coffee Association (SCA) designed the Agtron/SCAA Roast Color Classification System to provide the International coffee trade with a standardized method of classifying the degree of roast(Specialty Coffee Association website 2018). Figure 1-2 shows the eight roast classifications and their corresponding agtron tile numbers.

**Table 1-2 SCA Roast classifications with agtron tile numbers**

No.	Roast classification	Color disk Values
1	Very Light	Tile #95
2	Light	Tile #85
3	Moderately Light	Tile #75
4	Light Medium	Tile #65
5	Medium	Tile #55
6	Moderately Dark	Tile #45
7	Dark	Tile #35
8	Very Dark	Tile #25

Source: (Specialty Coffee Association website 2018)

Alternatively, colorimeters are also used to measure coffee bean color instead of assessing coffee bean visually. This can be done using the CIE  $L^*a^*b^*$  color space values of the coffee to provide information on lightness based on the obtained coordinates. CIE refers to Commission Internationale de l'Elclairage also known as the International Commission on Illumination the organization that created this color space model. The  $L^*$  measures the lightness or darkness of sample (contribution of black (0) or white (100)),  $a^*$  measures greenness/redness(between -60 to +60) and  $b^*$  measures the blueness/yellowness of roasted coffee sample (-60 to +60) (McGuire, 1992; Dmowski, P., & Dąbrowska, 2014)

Baggenstoss et al., (2008), Franca et al., (2009) and Ruosi et al., (2012)reported that much as in the coffee industry degree of roast is usually determined by measuring the color of the beans mainly because this is quick and easy to carry out, other parameters such as roasting temperature, loss in dry matter should be considered in order to obtain more accurate and reliable results.

The sensory characteristics of roasted coffee vary based on factors such as geographical location of origin, genetic cultivar, distinctive climates, differing processing methods, roasting process(roasting degree, roaster type, temperature and time and air-flow speed in the roasting compartment) coffee to water ratio and preparation methods (Farah, 2012; Sunarharum et al., 2014).

The compounds responsible for the sensory characteristics of the coffee brew are among those formed during roasting while other compounds are destroyed. During the coffee roasting process, the initial drying phase is mainly characterized by small endothermic reactions which lead to loss of free water, browning and increase in volume. The moisture content of the roasted coffee ranges between 1.5%-5% and this depends on the roasting degree attained. The sucrose in the beans caramelizes when their internal temperature reaches 130°C which explains the yellowish color of the beans. With the bean temperature increasing beyond 160°C, the color changes to light brown and the beans further increase in volume(Buffo and Cardelli-Freire, 2004; Farah, 2012). The aroma and flavor formed is a result of the endothermic and exothermic reactions when the coffee beans reach a temperature of about 190°C. Some of the free amino acids and peptides are used in the Strecker degradation while other amino acids and sucrose are involved in the Maillard reactions and this results in the bean color change from light brown to almost black. At this point, air or water is used to rapidly cool the coffee beans and consequently stopping the exothermic reactions(Buffo and Cardelli-Freire, 2004; Farah, 2012).

#### ***Physical-chemical characteristics of roasted coffee beans***

Table 1-3 shows that roasted Robusta beans have a higher chlorogenic acid content than roasted Arabica beans. During the coffee roasting process, the total chlorogenic acids are significantly reduced to about 50% at the medium level and in very small quantities at the dark level (Buffo and Cardelli-Freire, 2004; Farah, 2012). The characteristic brown color of coffee beans is explained by the formation of the intermediate and high molecular weight melanoidins during roasting. These melanoidins are produced by the Maillard reactions that occur between the proteins and carbohydrates in the presence of chlorogenic acids. Arabica and Robusta green beans have different chemical compositions and consequently varying aroma and flavor profiles when roasted. For example; Chlorogenic acids like feruloylquinic acids and caffeoylquinic acids that are found in Robusta roasted beans are 1.5-2 times higher in concentration as compared to those in Arabica beans(Farah, 2012; Sunarharum et al., 2014; Jeszka-Skowron et al., 2016). Chlorogenic acids



contribute to the bitter taste, acidity and astringent flavor of the coffee when it is brewed(Farah, 2012). In addition, chlorogenic acids act as precursors to the formation of phenols and catechols. Caffeine a stimulant of the methylxanthine class is heat stable has bitter sensory characteristics as such accounts for about 10% bitterness of coffee brew. Roasted Robusta beans contain two times the caffeine concentration contained in Arabica beans(Farah, 2012; Sunarharum et al., 2014).

Trigonelline an alkaloid also contributes to the bitterness of coffee brew. Caffeine is not degraded during coffee roasting however trigonelline is and this produces nicotinic acid and other volatile compounds such as the pyridines and pyrroles. Trigonelline and proteins (through Maillard reactions) act as precursors for the formation of volatile compounds such as pyridines, pyrroles, and pyrazines. The pyrazines, pyrroles, and pyridines are responsible for the Nutty, Roasted, Walnut, Toasty aromas. Arabica green beans contain more sucrose than Robusta green beans. This sucrose contributes to the acidity of the coffee brew after roasting. In part, this is the reason Arabica coffee has superior aroma and flavor as compared to corresponding Robusta coffee. The carbohydrates including the soluble polysaccharides are broken down during the roasting process to produce furans that explain the Sweet aromatics, Caramel, and Burnt aromas of coffee brew(Farah, 2012; Sunarharum et al., 2014). Lactic acids and acetic acids are responsible for the Fruity, winey, and Fermented aromas(Sunarharum et al., 2014).

The high molecular weight polysaccharides present in the roasted beans are responsible for the viscosity(body) of coffee brew (Farah, 2012).

**Table 1-3 Average chemical composition of roasted Arabica and Robusta coffee beans**

<b>Compounds</b>	<b>Concentration(g/100 g)</b>	
	<b>Arabica</b>	<b>Robusta</b>
Carbohydrates/fiber		
Sucrose	4.2-tr	1.6-tr
Reducing sugars	0.3	0.3
Polysaccharides (arabinogalactan, manna and glucan)	31-33	37.0
Caffeine	1.1-1.3	2.4-2.5
Trigonelline	1.2-0.2	0.7-0.3
Nitrogenous compounds		
Protein	7.5-10	7.5-10
Free amino acids	ND	ND
Melanoidins	25.0	25.0
Nicotinic acid	0.016-0.026	0.014-0.025
Lipids		

Coffee oil(triglycerides with unsaponifiables)	17.0	11.0
Diterpene esters	0.9	0.2
Minerals	4.5	4.7
Acids and esters		
Chlorogenic acids	1.9-2.5	3.3-3.8
Lignin	3.0	3.0
Pectins	2.0	2.0

Source: (Farah, 2012)

\*ND, not detected

## **Cold brewing methods**

Coffee is usually brewed using hot water to make its constituents more soluble. The sensory characteristics of brewed coffee are dependent on a number of factors such as origin and species variety of the roasted coffee beans, roasting degree, grind level of bean, coffee to water ratio, brew water hardness and temperature, length of contact time and level of agitation during extraction process and the type of filter material (Barone and Roberts, 1996; Sanchez and Chambers, 2015; Lane et al., 2017). The high temperature usually used in the extraction process increases the volatility of several of the chemical compounds that account for the sensory attributes in coffee (Albanese et al., 2009; Moon et al., 2009; Farah, 2012; Salamanca et al., 2017). In recent years, there has been a continued desire by consumers for more high-quality coffees with distinctive sensory characteristics. An example of such coffees is the cold brew which has become popular in the market today (Belanich, 2017; “Narino 70 Cold Brew,” 2017; National Coffee Association, 2018). Recently Roast magazine reported a 460% increase in retail sales of refrigerated cold brew coffee from 2015 to 2017. This can be attributed to the increased awareness and demand for the cold-brewed coffee (Belanich, 2017; “Narino 70 Cold Brew,” 2017).

The cold brewing system originated in the 1600s by the Dutch traders who employed this technique to enable them to transport the coffee brew that was intended for future consumption during their long journeys. It so happens to be that during the same era, the Japanese community in Kyoto began making cold brew coffee in addition to their tradition of cold-brewing tea. Cold brew coffee is brewed by utilizing time to extract the aromas and flavors of roasted coffee grounds. This slow extraction occurs over a longer period of time. For instance, the Full-immersion method requires between 8 to 24 hours at low temperatures (20 to 25°C or colder). The slow extraction process

improves the retention of the flavonoids by the cold-brewed coffee(Albanese et al., 2009; Lane et al., 2017; Salamanca et al., 2017). Cold brews are more flavorful, smoother and less acidic than the hot brew coffees that are produced using the traditional brew process that relies on heat as the brewing factor(“cold brew: the hottest coffee,” 2016). The increased demand for cold brew can be further explained by the growing one-time purchases together with the subsequent same unit sales all arising from the consumers' increased interest to try. Cold brew coffees can be termed as part of the third wave the coffee movement(Aylward, 2016; “Narino 70 Cold Brew,” 2017).

There are two main cold-brewing methods. The full immersion method and the slow dripping method. The immersion method involves fully steeping the coarse-ground coffee in water for upwards of 8 to 24 hours. This method relies on dispersion and diffusion to extract the soluble components from the coffee grounds into the water. The brew is separated from the spent grounds by filtration. A household-cold brewer system that uses this method is the Toddy brewer system that employs a felt filter to separate the cold-brew from the spent grounds(Toddy website, 2017). The slow-dripping method, on the other hand, involves water permeating through the coffee grounds at about one drop per second. The slow drip method relies on increased agitation and increased surface area of the coffee grounds for extraction(Uman et al., 2016). This method can last between 3 to 24 hours depending on the desired volume and concentration of the cold-brew. An example of such cold brewer systems is the Yama cold-brew brewer system(Prima-coffee.com).

### **Coffee to water ratio for cold brews**

The standard for the preparation of green coffee samples for use in the sensory analysis that was developed by the International Organization for Standardization recommends using a ratio in the range of 5-9 g per 100 ml of water for hot brew preparation(ISO 6668:2008). Using a very low C2WR can lead to over-extraction of the coffee resulting in a watery dull flavor. On the other hand, a very high C2WR depending on the methods used could result in poor extraction due to over-compaction and this normally occurs when using the slow-drip method (Andueza et al., 2007). Thus, the extraction process during cold brewing is greatly influenced by the coffee to water ratio (C2WR). In industry when brewing coffee using the cold water extraction process, a higher C2WR is normally applied. This is due to the fact that cold brew extracts are mainly produced as concentrates. The concentrates can then be watered down using ice cubes or hot

water and or milk or cream depending on the consumer preferences. (“cold brew: the hottest coffee,” 2016)

### **Sensory analysis of cold brewed coffee**

With an aim of improving the description of terminology used in sensory evaluation of coffee, Chambers et al., (2016) developed a quantifiable coffee lexicon that can be used to better describe the sensory characteristics of coffee in any part of the world. As long as the panelists are properly trained, the findings of the studies that use the lexicon are reproducible. Each attribute had at least one reference. These references were used as approximate scales to guide the panelists during the sensory evaluation. The intensity scoring of the references was based on a 15 point scale with 0.5 increments. The developed terminology and corresponding references in the established lexicon were used by Adhikari et al., (2017) in a coffee study that concluded that the consumption temperature has a significant impact on the flavor properties of hot brewed coffee. Various other studies have been carried out to determine the effects of different processes, and conditions on the sensory properties of hot- brewed coffee. For example, Sanchez and Chambers, (2015) studied the effect of brewing method on the flavor and mouthfeel attributes of coffee. They found that the intensities of both flavor and mouthfeel attributes varied depending on the brewing method that was used to prepare the coffee.

Lane et al., (2017) conducted a study that employed High-Performance Liquid Chromatography (HPLC) to determine if cold brewed coffee is more flavorful than hot brewed coffee. The result showed that similar levels of caffeine were produced when coffee samples were either cold-brewed or hot-brewed. The study further suggested that cold brewed coffee had a longer shelf life as it sustained most of its flavor components (more flavorful) as compared to the corresponding hot brewed coffee samples.

Kim and others (2014) investigated the composition profile of flavor-contributing nonvolatile chemical components such as chlorogenic acid, trigonelline, and caffeine as well as the sensory characterization of cold brew coffee that was made using full immersion and slow-dripping methods and time. After analysis with High-Performance Liquid Chromatography (HPLC), the results showed a significant interaction effect between the extraction time (3, 6, 9 and 18 h) and extraction methods (steeping and dripping) and that the intensities of the non-volatile chemical components were different for cold brewing by steeping or dripping. Furthermore, coffee samples

differed on intensities for sensory characteristics such as winery, chocolatey, acidity, sweetness, body, bitterness, and aftertaste for the two cold brewing methods when they were evaluated using the quantitative descriptive analysis (QDA) method( Kim, AR Kim, 2014). However, only 7 attributes were evaluated of which some like “body”, “acidity” do not appropriately describe the sensory characteristics of cold-brewed coffee while supposedly there are many more sensory attributes that can suitably be used to describe cold-brewed coffee. In addition, the level of general descriptive sensory training of the panel and the descriptive sensory method used do not provide for replicability of the results.

Despite the increasing prevalence of cold brewed coffee on the market, few published research currently exists on the impact of the different factors on the sensory characteristics of cold brew.

### **Research objectives**

In recent years, there has been a continued desire by consumers for more high-quality coffees with distinctive sensory characteristics. Cold brewed coffee which has become popular in the market today is an example of such coffee. Although previously published research studied impacts on the sensory attributes of brewed coffee, most of them focused on hot brewed coffee while others used instrumental analysis such as High-Performance Liquid Chromatography (HPLC) and not descriptive sensory evaluation methods. This study however used highly trained descriptive sensory panelists who evaluated cold brew coffee samples., The objectives of this study were to determine the impact of a) degree of roasting, b) coffee to water ratio (C2WR) and c) brewing methods on cold brew coffee from d) Ugandan coffee beans. Four different Uganda samples of which 2 were Arabica and other 2 were Robusta samples were used. Medium and dark roast levels and 8g and 12 g/100 ml coffee to water ratios were considered for this study. Two cold brewing methods (slow-drip and full-immersion) were employed to extract the coffee samples. A total of 42 attributes from the living coffee lexicon were used to describe the coffee samples (Chambers et al., 2016)

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## **Chapter 2 - Determining The Impact Of Roasting Degree, Coffee To Water Ratio And Brewing Method On The Sensory Characteristics Of Cold Brew Ugandan Coffee**

### **Abstract**

In today's market, there is a growing demand for high-quality coffee with distinctive sensory characteristics. An example of such coffees is the cold brew which has become quite popular. Despite the increasing prevalence of cold drip/brewed coffee, little-published research exists on the factors that impact the sensory characteristics of cold brew coffee. The objectives of this study were to determine the impact of a) degree of roasting, b) coffee to water ratio (C2WR) and c) brewing methods on cold brew coffee from d) Ugandan coffee beans. Four distinct coffee samples, sourced from different lowland and mountainous regions in Uganda, were roasted and tested using a factorial design that allowed comparison of all main factors (a-d) and their interactions. The samples were evaluated by a highly trained sensory panel based on 42 attributes from a previously published coffee lexicon. Results showed that all aspects studied (Ugandan variety, roast degree, C2WR, and brewing method) had an impact on most of the attributes. For example, Robusta coffees generally had a more bitter taste than Arabica coffees and the Dark roast samples generally were more bitter than the Medium roast coffees. In addition, coffee samples that were brewed using a higher coffee to water ratio (C2WR) generally were more bitter than the coffees that were brewed using a lower C2WR. However, although most of the main effects had a significant impact, their effects were mitigated by their interaction with other factors. For example, Medium roast Robusta that was slow-dripped with a high C2WR had a more bitter taste than the corresponding Arabica samples however when the Medium roast Robusta was steeped with a high C2WR it had a similar bitter intensity with the corresponding Arabica samples. Thus, although major impacts are critical, individual sample combinations must be considered when evaluating coffee samples for their impact on the sensory characteristics.

### **Practical application**

This study suggests the need to develop a group of profiles such as cocoa-like, fruity, chocolate/dark chocolate-like instead of marketing Ugandan coffee as just “Arabica” or “Robusta”

or with a cupping score. This can ensure consistency and effectively promote Ugandan coffee as a flavor experience in the growing specialty markets.

## **Introduction**

Coffee is the most traded food product in the world. In the coffee year 2016/17, global coffee production was 160.5 million 60-kg bags and total exports were 112.4 million 60-kg bags (USDA, 2017). Coffee remains the most widely consumed beverage in the world (National Coffee Association, 2018). The world coffee consumption for the coffee year 2016/17 was estimated at 155.06 million bags and the main importing countries are European Union, United States, Japan, and the Russian Federation (ICO, 2017). Consumption of coffee has increased worldwide and this can be attributed to improved breeding, advancement of specialty coffees, and increased awareness of the benefits of long-term coffee consumption. More consumers are drinking coffee because of its characteristic flavor and aroma and also due to the benefits of its antioxidant and physiological properties (Dórea and da Costa, 2005; Adriana, 2009).

The coffee tree belongs to the genus *Coffea* in the Rubiaceae family. *Coffea arabica* (Arabica) and *Coffea canephora* (Robusta) are the two species that are of economic significance out of over 80 coffee species (Adriana, 2009). Arabica coffee accounts for approximately 60-70% of the global production and Robusta accounts for the other proportion. Arabica coffee plants vary from Robusta plants in their physical features, the required growing climate, and chemical composition of the green beans. Arabica green beans have higher concentrations of sucrose, and coffee oil while Robusta green beans have higher concentrations of caffeine, chlorogenic acids, minerals, polysaccharides, and peptides (Farah, 2012).

Uganda is Africa's second-largest coffee producer after Ethiopia and the continent's largest coffee exporter with average total exports at 4.0 million 60-kg bags in the 2016/17 coffee year (USDA, 2017). Coffee remains a major foreign exchange earner in Uganda and a key source of income to an estimated 500,000 smallholder farmer households (Baffes, 2006; Snipes, 2017). Robusta and Arabica coffees account for 80% and 20% of the country's annual production respectively. Over 95% of Uganda's coffee is exported as green beans through direct sales to buyers mainly in the European Union, North America, and Asia. The value of Uganda's coffee has however dropped considerably over the years mainly due to unsustainable and limited competitiveness at the International market (Kufa et al., 2011). According to UCDA website, (2018), the government of Uganda in 2017 developed a roadmap to achieve its objective of increasing the country's

production from an average of 4.0 million 60-kg bags to 20.0 million 60-kg bags by 2025. To bring about the necessary change in the coffee sector, a number of initiatives were established. Key among these was to build Ugandan coffee as a lead-brand at the international market and to increase its value by 15%.

Coffee is traditionally brewed using hot water to make its constituents more soluble. The sensory characteristics of brewed coffee are dependent on a number of factors such as source and species variety of the roasted coffee beans, roasting degree, grind level of bean, coffee to water ratio, brew water hardness and temperature, length of contact time and level of agitation during extraction process and the type of filter material (Barone and Roberts, 1996).

In recent years however, there has been a continued desire by consumers for more high-quality coffees with distinctive sensory characteristics. An example of such coffees is the cold brew which has become popular in the market today (Belanich, 2017; “Narino 70 Cold Brew,” 2017; National Coffee Association, 2018). Roast magazine recently reported a 460% increase in retail sales of refrigerated cold brew coffee from the year 2015 to 2017. The increased demand for cold brew can be further explained by the growing one-time purchases and the subsequent same unit sales all arising from the consumers’ increased interest to try different coffee innovations.

Cold brew coffee (also known as Dutch coffee, Kyoto-style coffee, or cold water extract coffee) is coffee that is brewed using the time to extract the aromas and flavors of roasted coffee grounds. The extended extraction period can last 3 to 24 hours. Bearing in mind that heat is not used in this extraction process, less of the coffee constituents that are more soluble in water at high temperatures will be extracted and found in the brew. This explains why usually when cold brewing a higher coffee to water ratio is applied. The cold brewing system originated in the 1600s by the Dutch traders who employed this technique to enable them to transport the coffee brew that they planned on consuming at a future time. During the same era, the Japanese in Kyoto that is located in the Kansai region of Japan began making cold brew coffee in addition to their traditional cold-brew tea.

A few studies have been conducted to determine the effects of different factors on the sensory properties of coffee brew. For example, Sanchez and Chambers (2015) studied the effect of brewing method on the flavor and mouthfeel attributes of coffee. They found that the intensities of both flavor and mouthfeel attributes varied depending on the brewing method that was used to

prepare the coffee. Another study suggested that the consumption temperature has a significant impact on the flavor properties of hot brewed coffee (Adhikari et al., 2017).

Lane et al., (2017) used high-performance liquid chromatography to study the levels of caffeine content in coffees that were prepared using cold-brewing and hot-brewing methods. The results showed that cold-brewing methods produced coffee brew with similar caffeine content as brew produced when the hot-brewing methods were used but then the slow extraction process at low temperature improved on the retention of the flavonoids and was responsible for the extended shelf life for the cold brew as compared to the corresponding hot brew coffee. The high temperatures employed during the extraction process are responsible for the increased volatility of several of the chemical compounds that account for the sensory properties in the hot brew (Albanese et al., 2009; Salamanca et al., 2017).

Kim and others (2014) investigated the composition profile of flavor-contributing nonvolatile chemical components such as chlorogenic acid, trigonelline, and caffeine as well as the sensory characterization of cold brew coffee that was made using full immersion and slow-dripping methods and time. After analysis with High-Performance Liquid Chromatography (HPLC), the results showed a significant interaction effect between the extraction time (3, 6, 9 and 18 h) and extraction methods (steeping and dripping) and that the intensities of the non-volatile chemical components were different for cold brewing by steeping or dripping. Furthermore, coffee samples differed on intensities for sensory characteristics such as winery, chocolatey, acidity, sweetness, body, bitterness, and aftertaste for the two cold brewing methods when they were evaluated using the quantitative descriptive analysis (QDA) method( Kim, AR Kim, 2014). However, only 7 attributes were evaluated of which some like “body”, and “acidity” do not appropriately describe the sensory characteristics of brewed coffee while supposedly there are many more sensory attributes that can suitably be used to describe cold-brewed coffee. In addition, the level of training of the panel and the descriptive sensory method used do not provide for replicability of the results.

Despite the increasing prevalence of cold brew, very little research has been conducted using a trained descriptive sensory panel to assess the effect of various factors on the sensory properties of cold brew coffee. Thus, the purpose of this study was to determine the impact of four factors; coffee bean variety, roasting degree, coffee to water ratio and brewing method on the sensory attributes of cold brew coffee. Four Uganda green coffee samples (2 Arabica and 2 Robusta), two

degrees of roasting (Medium and Dark), two coffee to water ratios (8 g and 12 g/ 100 ml of water), and two brewing methods (Slow-drip and full-immersion) were used for this study.

## Materials and methods

### Coffee samples

A total of four (4) Ugandan green coffee samples, 2 Arabica and 2 Robusta samples were used in this study. For the Arabica samples, one was dry-processed while the other was wet- processed and the same applied to the Robusta samples. The coffee sample origins were four coffee farmer associations located in different coffee growing regions with varying terroirs. The coffee samples were provided by the coffee farmers' organization in Uganda, NUCAFE. The details of the different coffees used for this study along with their specifications are shown in Table 2-1. The moisture content of the samples was measured using an AP6060-001AG Moisture Analyzer (Sinar Technology website) for which all four samples ranged between 12.5-12.9%.

**Table 2-1 Coffee samples used for this study**

<b>Sample Label</b>	<b>Farmer Association</b>	<b>Coffee Type</b>	<b>Grade</b>	<b>Processing Method</b>	<b>Moisture Content</b>	<b>Region</b>	<b>Altitude/m</b>
AW	Bufumbo Organic Coffee Farmers Association	Arabica	AA	Wet-Processed	12.5%	Bugisu, Mbale Eastern Uganda	1945-2044
AD	Kabonero Mountaneous Coffee Growers Association	Arabica	ungraded	Dry Processed	12.9%	Kabarole, Rwenzori Western Uganda	1480- 1532
RW	Mabira Coffee Farmers Association	Robusta	1800	Wet-Processed	12.6%	Mabira, Central Uganda	1070-1340
RD	Buwama Coffee Farmers Association	Robusta	1800	Dry Processed	12.6%	Bunjako, Buwama, Central Uganda	1137-1185

### Sample preparation

#### Roasting degree

Each green coffee sample was roasted the week before the start of the sensory evaluation using a Diedrich IR-2.5 (2.5 Kg roaster made in the USA) at two levels. The two degrees of roasting were Medium and Dark and these were determined basing on the color of the roasted beans that was measured using CR-410 colorimeter (KONICA MINOLTA INC. made in Japan). The color of the beans was evaluated according to the CIE L\*, a\* and b\* color space values of roasted coffee samples, where L\* measures the lightness or darkness of sample (contribution of black (0) or white (100)). a\* measures greenness/redness(between -60 to +60) and b\* measures the blueness/yellowness of roasted coffee sample (-60 to +60) (McGuire, 1992; Dmowski, P., & Dąbrowska, 2014). The average values of chromatic parameters for the roasted coffee samples are shown in Table 2-2.

**Table 2-2 Average values of Chromatic parameters of the roasted samples. Each value represents the data mean (n=3)**

Sample label	Coffee Type	Roast Level	L*	a*	b*
AW	Arabica	Medium	23.43	5.03	4.96
AW	Arabica	Dark	21.30	3.90	2.69
AD	Arabica	Medium	23.81	5.62	5.46
AD	Arabica	Dark	21.31	4.44	3.14
RW	Robusta	Medium	23.70	5.07	4.58
RW	Robusta	Dark	22.51	3.90	2.99
RD	Robusta	Medium	24.26	4.85	4.86
RD	Robusta	Dark	21.68	3.71	2.64

After the coffees were roasted, they were cooled and placed in Food Saver vacuum bags and sealed using a Food Saver Heat-Seal Vacuum Sealing System (Sunbeam Products Inc., Boca Raton, FL, USA). The roasted beans were then flash frozen before being placed in a freezer set at 0<sup>0</sup> F. The roasted samples were retrieved from the freezer and ground not more than 15 minutes before the start of the brewing process(Standard Specification for Freezers, Ice Cream, Soft Serve, Shake BT - Standard Specification for Freezers, Ice Cream, Soft Serve, Shake, 15AD).

### **Coffee to water ratio**

Two coffee to water ratios that is 8 g and 12 g of coffee per 100 ml of water were used. The 8 g per 100 ml of water was employed in reference to the standard for the preparation of green coffee samples for use in the sensory analysis that was developed by the International Organization for Standardization (ISO 6668:2008). The standard recommends using a ratio in the range of 5-9 g of coffee per 100 ml of water when preparing coffee for sensory analysis studies. Consideration was put in the fact that cold brew is usually prepared using a higher coffee to water ratio than regular hot brewed coffee. And as such, a second coffee to water ratio, 12 g per 100 ml was applied to the samples that were used in the study ("cold brew: the hottest coffee," 2016). The coffee extraction was done using deionized filtered distilled water.

### **Brewing methods**

Coffee samples were ground not more than 15 minutes before the onset of the brewing process using a flat steel burr commercial grade coffee grinder, the Baratza Forte Brew Grinder (Baratza LLC, Bellevue, WA, USA). Standard Test sieves made by Gilson Company, Inc, USA were used to adjust the grinder to produce grind levels that suited the two cold brewing methods (Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves BT - Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves, 17AD; ASTM Standard E11, 2011; Tyler W.S, 2011).

One of the cold-brewing method used in this study is the Full-immersion or Steeping method. This method relies on dispersion and diffusion to extract the soluble components from the coffee grounds into the water. The dispersion process is very slow and because of this coffee extraction requires a long time (can last between 8 to 24 hours). The Toddy Cold Brew System was used to steep the coffee samples. The grinder was adjusted to grind level 10 (ASTM standard test sieve No. 16). The samples were prepared following the brewer instructions and the brew extraction containers were placed in a refrigerator set at 35°F for 16 hours (Toddy website, 2017). Slow-drip or dripping was the other method used to cold-brew the coffee samples. The soluble Yama cold coffee brewer (32 oz.) was used to drip the coffee samples. The grinder was adjusted to grind level 8 (ASTM standard test sieve No. 20). One-third of the water used in this method was in the form of frozen ice cubes while the other proportion was kept at room temperature. During brewing, the



ice cubes melted maintaining the temperature of the falling water between 30-35°F over a period of 3 hours. This method involves iced water dripping through coffee grounds. Unlike the full-immersion method, the slow drip method relies on increased agitation and increased surface area of the coffee grounds to extract the coffee components by the dropping water. The water falls at an average speed of 35-40 drops per minute onto a paper-filter that evenly distributes it over the pre-wetted coffee grounds. The cold water holds within it the coffee aroma and flavor components as it proceeds through the ceramic-filter and finally into a collecting container. Once the brewing process was done, the cold-brew was covered with a lid and placed in a refrigerator set at 35°F.

### **Standard References**

Four hot-brewed controls were used as standardized references for this study. Control (A) was Medium roast wet-processed Arabica (AW), Control (B) was Dark roast dry-processed Arabica (AD), Control (C) was Medium roast wet-processed Robusta(RW), and Control (D) was Dark roast dry-processed Robusta(RD).

The controls were brewed using the filtered infusion method with a coffee to water ratio of 7g per 100 ml of water(ISO 6668:2008). The Baratza Forte Brew Grinder (Baratza LLC, Bellevue, WA, USA) was adjusted to level 5(ASTM standard test sieve No. 30) and deionized water was heated to 98°C and poured over the grounds in a swirl motion using a gooseneck kettle to ensure all the grounds were wetted. The infusion was let to steep for 3 minutes after which it was strained using an ASTM standard test sieve No.50 (Gilson Company, Inc. USA) into a glass refrigerator pitcher and the lid placed on top (ISO 6668:2008; Chambers et al., 2016). The pitcher was immediately placed in a refrigerator and cooled to 35°F.

The cold brew samples and the reference standards were each served at temperatures ranging between 39-44°F to the panelists in 8 oz. Bodum canteen double-wall cooler glasses for sensory evaluation. The temperature of the coffee in the double-wall glasses was maintained using an ice-cube bath by placing the glasses in plastic bins and carefully surrounding them with ice cubes for the entire session. The temperature of the coffee was regularly measured using a ThermoMapen Mk4 thermometer (ThermoWorks, Inc, Website).

## **Panelists and Sensory evaluation procedure**

A highly trained panel that comprised of five (5) members from the Center for Sensory Analysis and Consumer Behavior at Kansas State University (Manhattan, Kansas) evaluated the cold brew samples using the modified flavor profile method. The panelists each had experience of 120 hr. of general descriptive analysis training and over 2000 hours of general descriptive sensory testing of beverages and other foods products including coffee and were familiar with the previously published coffee lexicon (Chambers et al., 2016). The panel had four days of 1.5 hr. orientation sessions that began with testing of the 11 attributes(woody, roasted, sour, sweet, sweet aromatics, green, bitter, nutty, fruity, floral, and fullness) recommended by researchers and world coffee research experts for sensory analysis of coffee varieties (Chambers et al., 2016). Thirty-one attributes were added to the initial eleven bringing the total to 42 attributes that were used to describe the cold brew Ugandan coffees samples. The panel used the consensus method and a 15 point scale with 0.5 increments to evaluate side by side and award scores to the hot-brewed control samples. The established attribute intensities of the four controls were then used as standard references during the following evaluation sessions. The ballot outlining the attributes, their definitions and their corresponding intensities for each of the standard references is provided in Appendix A.

The orientation sessions were followed by sixteen 1.5 hr. evaluation sessions where the 32 cold-brewed samples were evaluated individually, one at a time and in triplicate following a completely balanced randomized block design basing on a 15 point scale with 0.5 increments. Bagels, cream cheese, and tomato juice were used to cleanse the panelists' palates between each sample evaluation and a total of 6 samples were evaluated during each session. The cold-brewed samples were labeled with three-digit blinding codes and presented to the panelists for assessment. The panelists evaluated appearance (color intensity), aroma and flavor, aftertaste, and amplitude for every sample. For appearance, one-fourth cup of the sample was placed in a medium snifter and evaluated under uniform, shadow-free white light in accordance with ISO standard on the design of test rooms for sensory analysis (Standard, 1988). To denote aroma and flavor attributes, (a) and (f) were used respectively. The aroma and flavor attributes that were evaluated included: smoky(a)(f), ashy(a)(f), woody(a)(f), roasted(a)(f), sweet aromatics(a)(f), burnt(a)(f), acrid(a)(f), chocolate/Dark chocolate(a)(f), green(a)(f), nutty(a)(f), fruity(a)(f), floral(a)(f), cocoa(a)(f), fermented(a)(f), Musty/Earthy(a)(f), Stale(a)(f), sour taste, sweet taste, bitter taste, and mouth

drying and bitter aftertaste. The amplitude attributes that were assessed included: coffee ID, overall impact, blended and longevity.

## **Data Analysis**

The statistical program SAS version 9.4 (SAS Institute, Inc., Cary, NC) was used to conduct the mixed effects four-way model analysis of variance of the data with Least Square (LS) means. A significance level of  $p < 0.05$  was used. The results of the data analysis provided information on the impact of the main effects as well as the four-way and three-way interactions that statistically had significant impact on the sensory characteristics of the cold-brewed coffee samples. Scatter plots were used to illustrate the significant four-way and three-way interactions of the four factors

## **Results and Discussion**

### **Effect of main effects on the sensory attributes**

#### **Effect of coffee sample variety**

According to Oestreich-Janzen, (2010), and Sunarharum et al., (2014), the Robusta coffee variety has higher concentrations of chemical components such as chlorogenic acids, and proteins than Arabica variety in either green and roasted form and these do impact on the coffee-like sensory characteristics of the brew. For example, the Robusta samples evaluated in this research had a greater coffee ID or fullness as compared to the corresponding Arabica samples. The greater coffee ID in the Robusta cold brew can be explained by the higher levels of high molecular-weight polysaccharides present in the brew. It is inherent that Robusta beans contain more polysaccharides than Arabica beans. Results in this study also showed that cold-brewed Robusta samples had a darker brown brew color as compared to the Arabica samples. The color intensities can be explained by the presence of higher levels of the intermediate and high molecular weight melanoidins in the Robusta samples as compared to the Arabica samples. The melanoidins are brown colored polymers that are produced as a result of the non-enzymatic browning reactions during the coffee roasting process. Caramelization, the breakdown of carbohydrates under high temperatures contributes to the browning of the beans during coffee roasting (Chu and Institute of Food Technologists.; Farah, 2012). However, a larger proportion of melanoidins are produced by

the Maillard reactions that occur between the amino acids(proteins) and sugar(carbohydrates) in the presence of chlorogenic acids during the roasting process (Bekedam et al., 2008). It is worth noting that Robusta coffee has a higher chlorogenic acid and protein content than Arabica coffee. During the coffee roasting process, the total chlorogenic acid content is reduced to about 50% at the Medium level and in very small quantities at the Dark level. (Chu and Institute of Food Technologists.; Farah, 2012). This study presented results that are in accordance with the results presented by Vignoli et al., (2014) that also reported a higher level of melanoidins in Robusta than Arabica when the green coffee samples were roasted. Additionally, as expected the Robusta samples had a more bitter taste and higher intensities of a bitter aftertaste as compared to the Arabica samples. Farah, (2012) reported that trigonelline an alkaloid found in green coffee beans contributes to the bitterness of the brew and is broken down to pyridines, pyrroles, and nicotinic acid during the roasting process. Arabica bean variety contains more trigonelline than the Robusta variety however the contribution of trigonelline to bitterness is relatively small. Chlorogenic acids such as caffeoylquinic, and feruloylquinic acids contribute to the bitter taste of the coffee when it is roasted and brewed (Sunarharum et al., 2014). Caffeine a heat stable stimulant belonging to the methylxanthine class also has bitter sensory characteristics and as such accounts for about 10% bitterness of coffee brew(Clarke and Macrae, 1985). It so happens that roasted Robusta beans contain two times the caffeine concentration contained in Arabica beans(Farah, 2012; Vignoli et al., 2014). These higher levels of caffeine found in roasted Robusta samples together with the chlorogenic lactones produced as a result of the Maillard reactions between the carbohydrates and proteins in presence of the chlorogenic acids account for the higher intensity of bitterness as compared to the Arabica samples(Chu and Institute of Food Technologists.; Farah, 2012; Sunarharum et al., 2014). The brews of the Robusta samples were further characterized by higher intensities of musty/earthy flavor compared to the Arabica samples. According to Akiyama et al., (2007), pyrazines such as Ethyl pyrazine that is produced during the roasting process are associated with the earthy-like attribute in Robusta.

On the other hand, Arabica sample cold-brews were more blended as compared to the Robusta cold brew samples.

### **Effect of Roasting degree**

For the impact of roasting degree, it's not surprising that the Dark roast cold brew samples had greater roasted flavor as compared to the Medium roast cold brew samples. The roasted flavor in

the cold brew can be explained by the presence of thiols such as 2-furfuryl thiol which is a sulfur-containing compound found in roasted coffee beans (Sunarharum et al., 2014). The Dark roast samples were more bitter, had a greater overall impact, and also had higher intensities for Coffee fullness, and flavor attributes such as smoky, ashy, roasted, and acrid as compared to the Medium roast samples. As stated by Dulsat-Serra et al., (2016) thiols such as 2-Furfurylthiol that are produced as a result of Maillard reactions during the roasting process are responsible for the aroma characteristics such as roasted and coffee-like. An earlier study conducted by Bhumiratana et al., (2011) confirms the results of this study. They studied the evolution of sensory aroma attributes from coffee beans to brewed coffee. They reported that increase in the degree of roasting (from light to dark) resulted in higher intensities for flavor attributes such as roasted, coffee fullness, ashy, and acrid. Akiyama et al., (2005, 2007) found that smoky flavor intensities increased with the increased degree of roasting from Medium to Dark roast of the coffee samples. On the other hand medium, roasted samples showed more balance as they were more blended and had a shorter lasting experience in the mouth as compared to the Dark roasted samples (Farah, 2012; Sunarharum et al., 2014).

#### **Effect of coffee to water ratio**

As expected, the sensory experience of coffee samples which were brewed using a higher coffee to water ratio of 12 g per 100 ml lasted longer as compared to that of coffee samples that were brewed using the 8 g per 100 ml coffee to water ratio. Cold brew samples that were prepared with a high C2WR contained higher concentration levels of chemical components that impact on the sensory characteristics of the coffee sample. Majority of these chemical components are products of non-enzymatic browning reactions such as the Maillard reaction during coffee roasting. For instance, samples brewed with a high C2WR had a darker brown color, had a greater roasted flavor, were more bitter, and had a greater overall impact when compared to corresponding samples that were brewed using a low C2WR. Furthermore, samples brewed with a high C2WR had a greater bitter taste that lingered longer as compared to samples that were brewed using a low C2WR (Andueza et al., 2007).

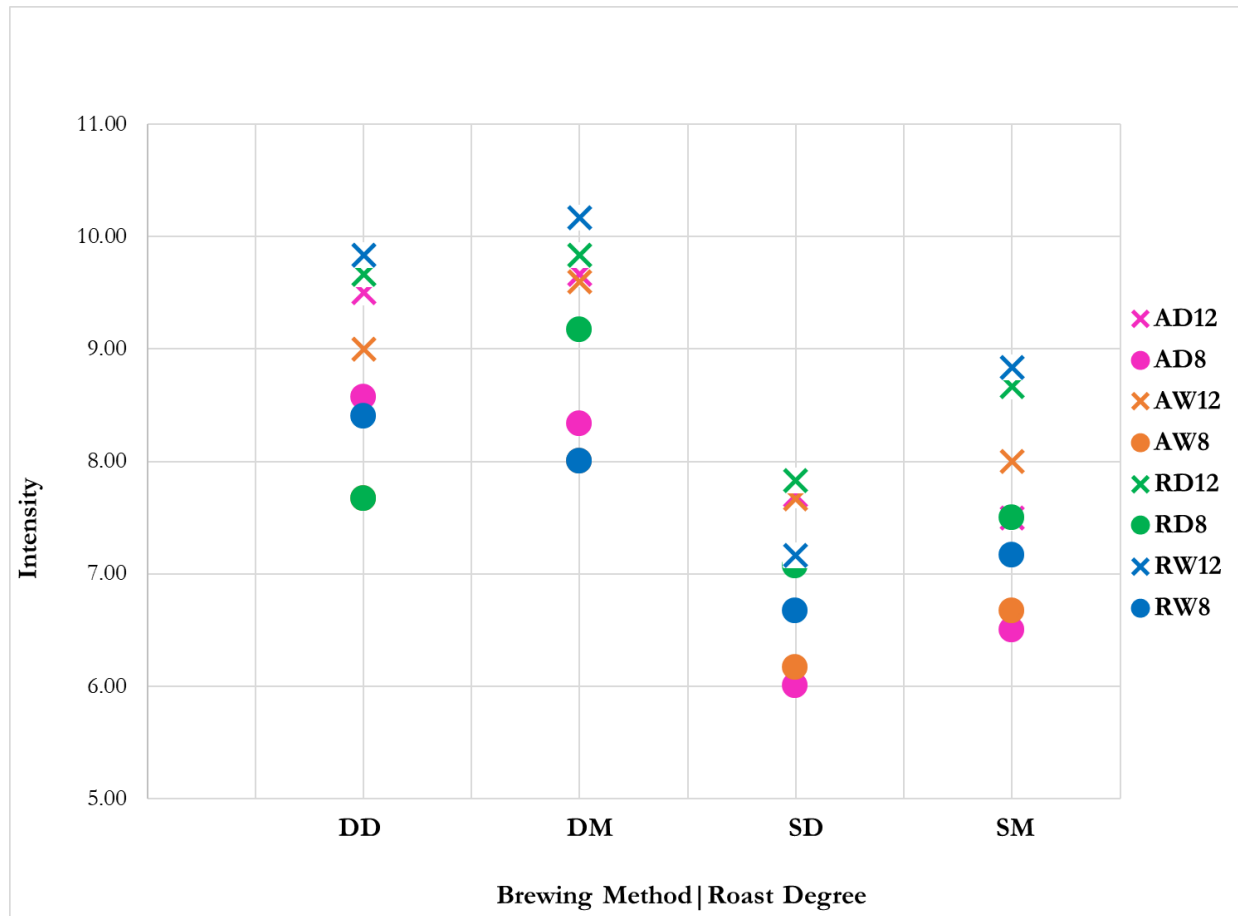
#### **Effect of brewing method**

Samples that were brewed using the slow-dripping method had a darker brown color, had higher intensities for flavor attributes such as roasted, bitter taste and bitter aftertaste as compared to the

samples that were brewed using the full-immersion method. The slow-drip method provides for increased agitation as the falling water relatively quickly takes hold of the soluble compounds such as the melanoidins, caffeine, and chlorogenic acids and solids in the coffee grounds during the extraction process. Full-immersion or steeping method mainly relies on dispersion and diffusion to extract the soluble compounds from the coffee grounds (Moon et al., 2009; Fuller and Rao, 2017). With the dripping method, a slightly-coarse (finer) grind level is employed as compared to the steeping method which increases the surface area of the coffee granules thus improving the solubility of the chemical compounds into the cold water during the extraction process (Uman et al., 2016). The samples that were dripped as a result had a greater coffee ID, and overall impact and lastingness as compared to samples that were steeped (Farah, 2012).

Table C-1 in Appendix C shows the analysis of variance (ANOVA) scores for the main effects.

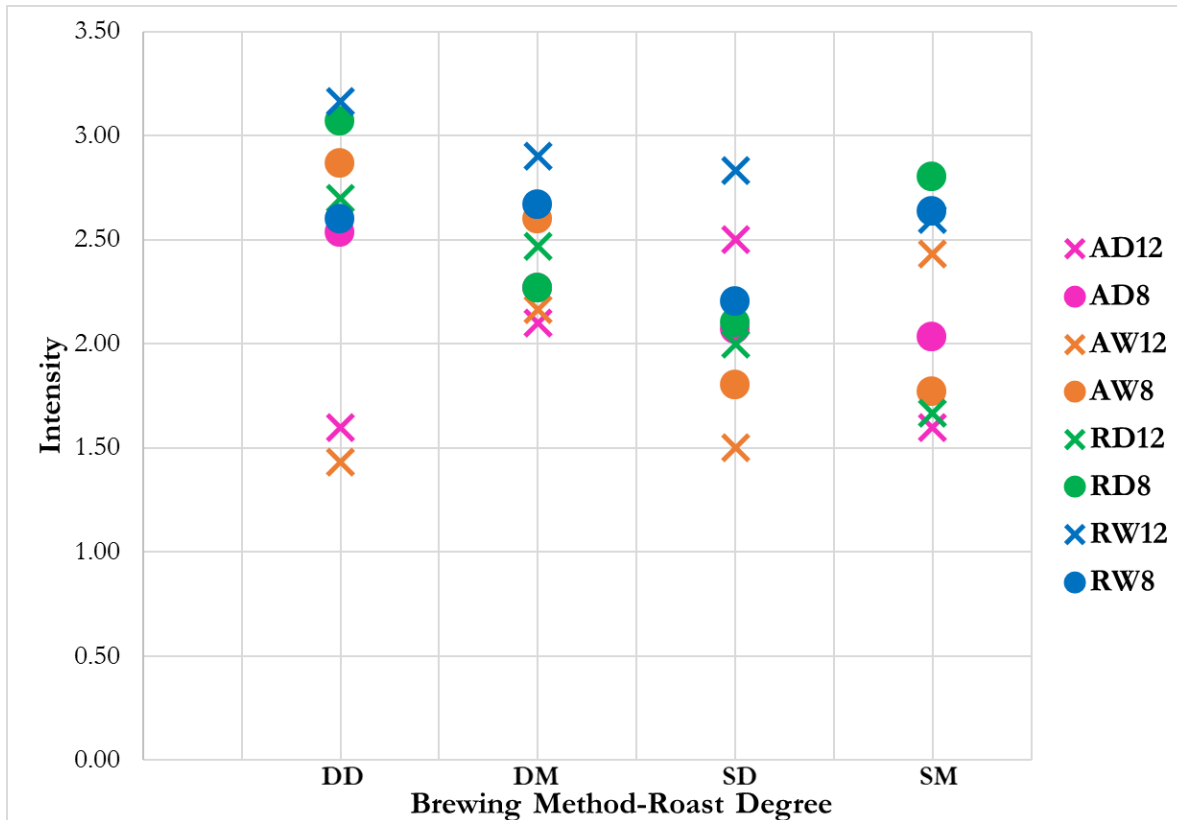
However, results of this study also suggested that the impact of one factor (coffee bean variety or roasting degree or coffee to water ratio or brewing method) on the sensory characteristics was dependent on the levels of the other factors. This was shown by the statistically significant four-way and three-way interaction effects among the factors. Sensory characteristics such as color intensity, longevity, balanced/blended, overall impact, bitter taste and bitter aftertaste, mouth drying(f), sour taste, fermented(a)(f), cocoa(a)(f), fruity(a)(f), nutty(a)(f), green(a)(f), chocolate/dark chocolate(a)(f), acrid(a)(f), roasted(a)(f), smoky(a)(f), woody(a)(f), stale(a), floral(a), burnt(a), and ashy aroma(a) all had significant four-way interactions. The musty/earthy aroma attribute and attributes such as coffee ID, sweet taste, stale(f), floral(f), burnt(f), sweet aromatics(f), ashy(f), and musty/earthy(f) had statistically significant three-way interaction effects.



**Figure 2-1 Four-way interaction for Color Intensity (DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)**

### Effect of the significant four-way interactions

Figure 2-1 shows that Dark roast Robusta that was steeped with a low C2WR had a darker brown brew color than the corresponding Arabica samples. However, when the Dark roast Robusta and Arabica samples were brewed by slow-dripping with a low C2WR, both Robusta and Arabica samples had similar brew color intensities.



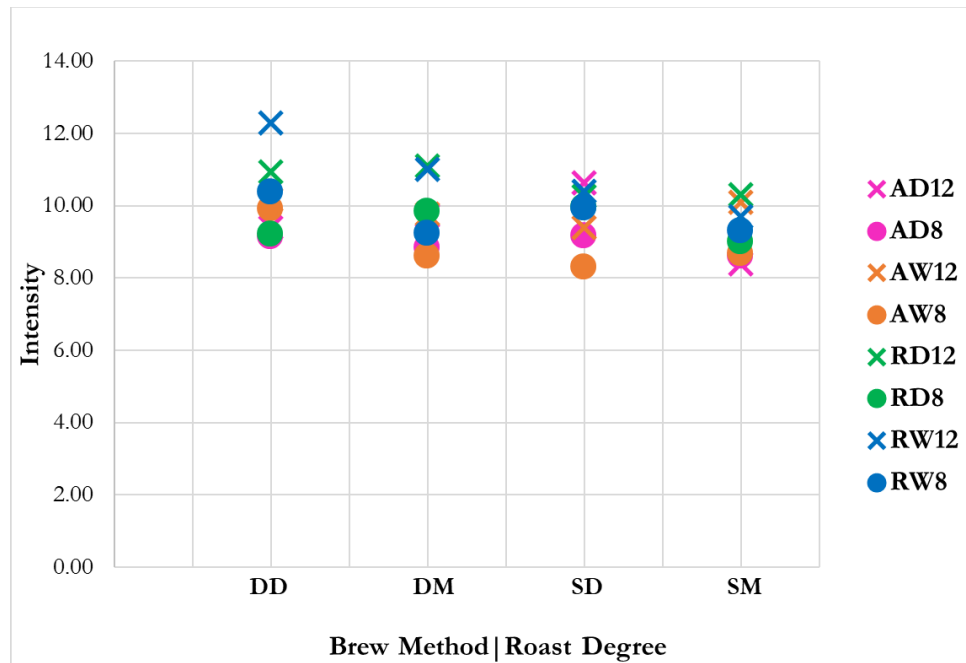
**Figure 2-2 Four-way interaction for Woody aroma (DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)**

Dark roast Robusta when slow-dripped with a high C2WR had a higher roasted and woody aroma than the corresponding Arabica samples but when steeped both the Arabica and Robusta had a similar intensity for roasted and woody aroma. The four-way interaction for woody aroma is illustrated in Figure 2-2.

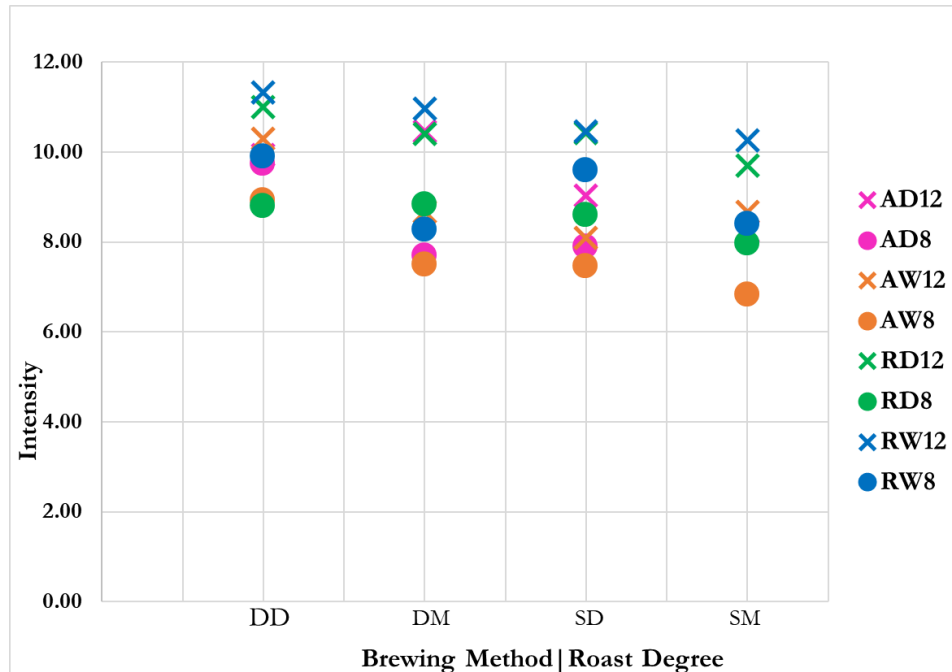
Medium roast Robusta samples that were slow-dripped with a high C2WR had a more bitter taste than the corresponding Arabica samples but when the medium roast Robusta was steeped with a high C2WR it had a matching bitter intensity with the corresponding Arabica samples as shown in Figure 2-3. Figure 2-4 shows that Medium roast Robusta that was steeped with a high C2WR had a higher overall impact than the corresponding Arabica samples, however, the Robusta and Arabica samples had a similar Overall impact when these samples were brewed by dripping. Furthermore, Medium roast Robusta that was steeped with a low C2WR had a higher intensity of attributes such as woody aroma, sour taste, and flavor attributes such as Chocolate/Dark Chocolate, acrid, cocoa, smoky, and woody and had a more intense bitter aftertaste and greater overall impact



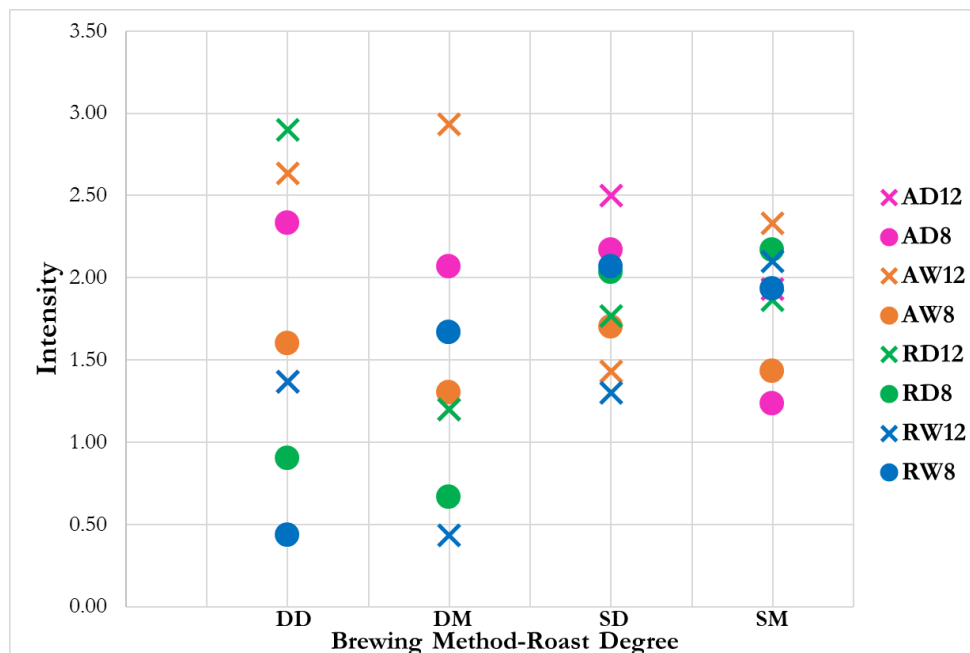
as compared to the corresponding Arabica samples. However, when this Arabica and Robusta were dripped, they had more similar intensities for attributes such as woody aroma, sour taste, acrid, cocoa, Chocolate/Dark Chocolate, smoky, woody flavor, bitter aftertaste and overall impact.



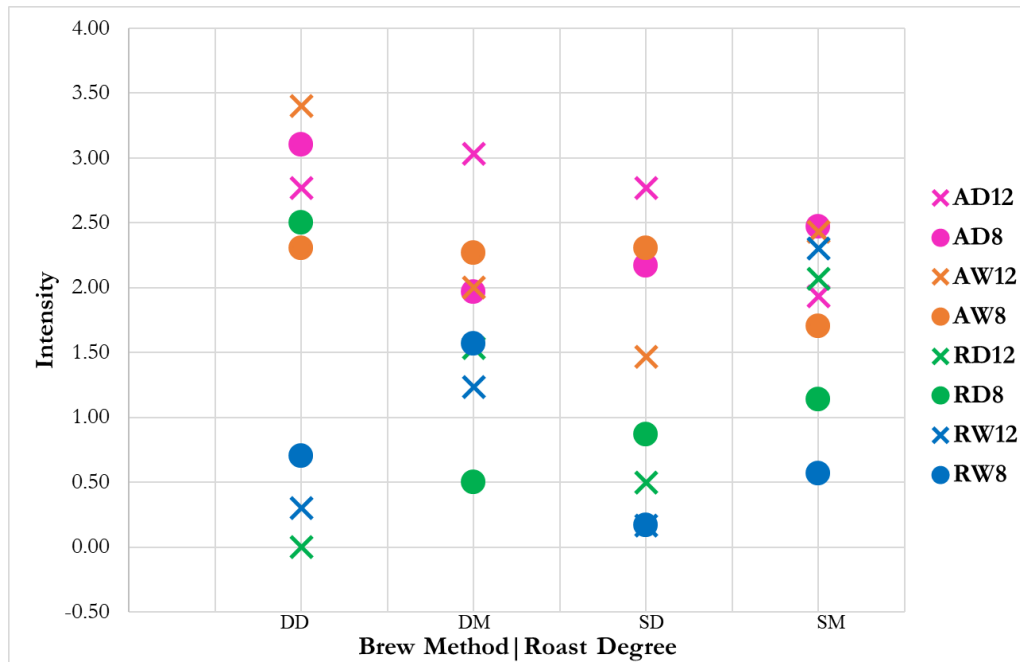
**Figure 2-3 Four-way interaction for Bitter taste (DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)**



**Figure 2-4 Four-way interaction for Overall Impact (DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)**

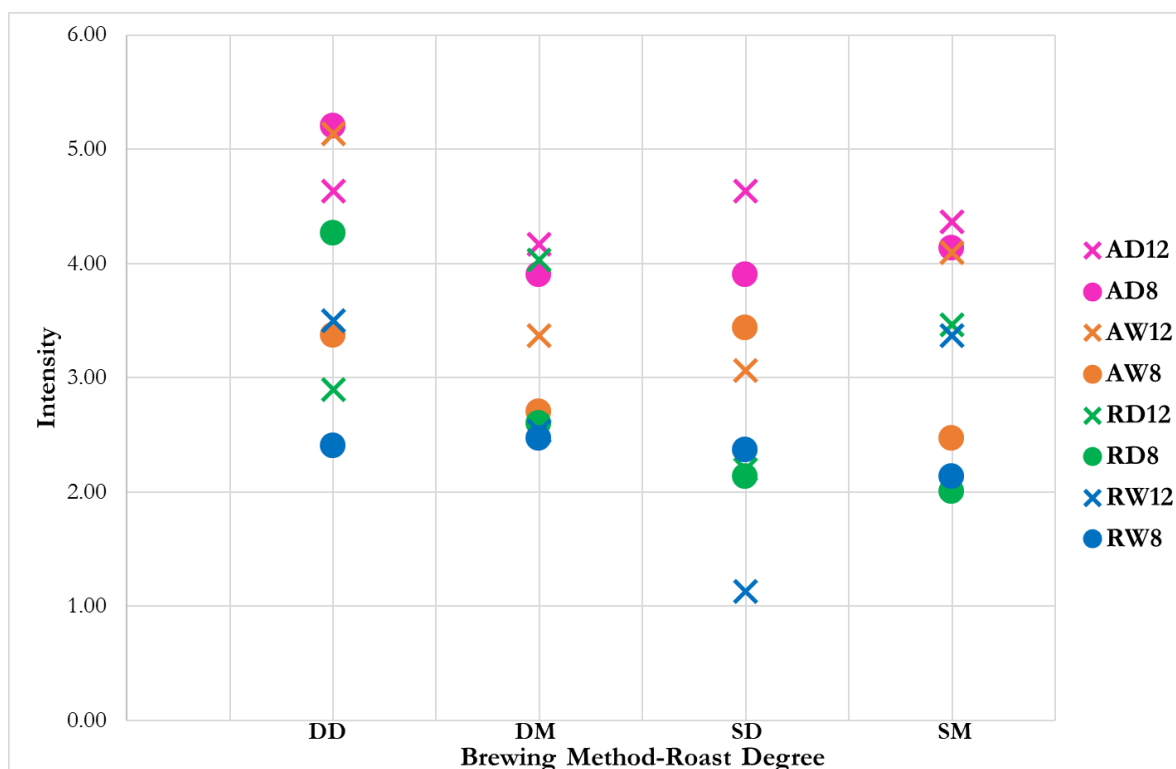


**Figure 2-5 Four-way interaction for Sour taste (DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)**



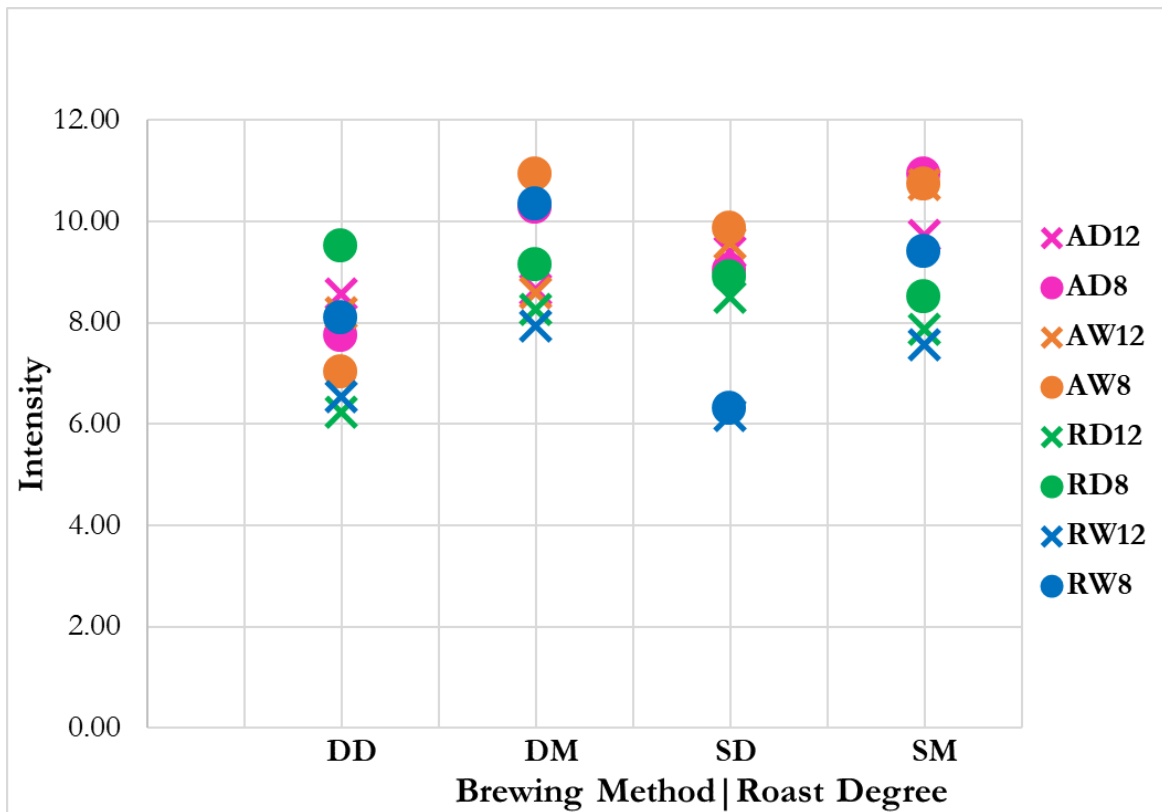
**Figure 2-6 Four-way interaction for Fruity flavor (DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)**

It is noteworthy to mention that Dark roast Arabica had a more intense fruity, and nutty aroma and had a higher fermented flavor when it was slow-dripped with a high C2WR as compared to dark Robusta that was prepared similarly. Dark roast Arabica that was steeped with a low C2WR upheld a higher fruity aroma and a higher intensity of fruity and fermented flavor when compared with the corresponding Robusta samples. However, there was no difference in intensities for fruity aroma, fruity flavor, and fermented flavor when the Arabica and Robusta samples were brewed using the slow-dripping method. The four-way interaction for fruity flavor attribute is shown in Figure 2-6.



**Figure 2-7 Four-way interaction for Fermented flavor (DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)**

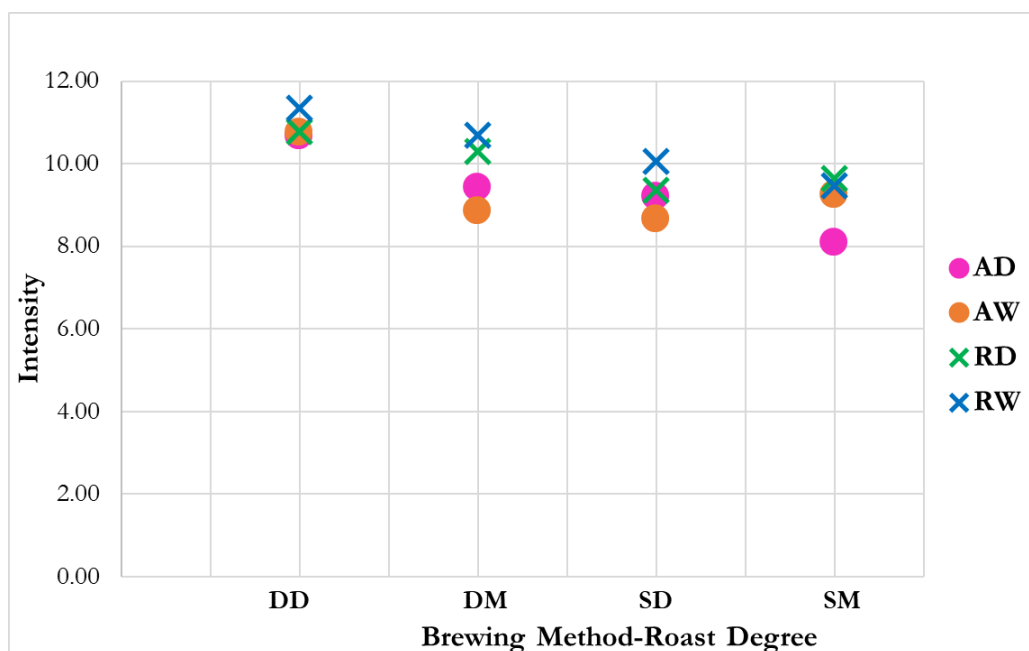
When Medium roast Arabica was steeped with a high C2WR, the samples had a higher intensity for fermented flavor and were more balanced/blended than the corresponding Robusta samples. But then when the samples were slow-dripped, there was no difference in fermented flavor and blendedness/balance intensities between these Arabica and Robusta samples. Figures 2-7 and 2-8 show the four-way interaction for fermented flavor and balanced/blended attributes respectively.



**Figure 2-8 Four-way interaction for Balanced/Blended (DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)**

### **Effect of the significant three-way interactions**

Figure 2-9 shows that Medium roast Robusta that was brewed by slow-dripping had a higher Coffee ID than the corresponding Arabica samples. However, when steeped the Robusta and Arabica samples had similar coffee ID intensities.



**Figure 2-9 Three-way interaction for Coffee ID/Fullness (DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)**

It is also worth noting that Medium roast Robusta that was steeped had a more burnt flavor than the corresponding Arabica samples. Dark roast Robusta that was steeped had a higher ashy, burnt flavor when compared with the corresponding Arabica samples. Then when the same samples were slow-dripped, they had similar intensities for ashy and burnt flavor attributes.

## Conclusion

The factors (at different levels) that were studied that is bean variety, roasting degree, coffee to water ratio and brewing method were found to have major impacts on almost all the 42 sensory attributes that were evaluated. But then, the effects of these major impacts were mitigated by the interactions of these factors that were under investigation. The findings here recommend the consideration of the factor combinations when assessing their impact on the sensory characteristics of coffee. For instance today Uganda promotes and markets its coffees with a cupping score or just as either “Arabica” or “Robusta”. This study proposes a need to create a group of coffee flavor profiles such as chocolate/dark chocolate-like, cocoa-like, fruity-like, more-balanced/blended, and high-coffee ID as this will ensure consistency in the Ugandan coffee industry by providing control and more understanding of the sensory characteristics of coffee. Furthermore, the coffee profiles

that will be developed will establish relationships among sensory characteristics that could be illustrated using coffee flavor trees. By controlling the agronomical practices, primary, secondary and tertiary processes, the Ugandan coffee industry will effectively promote its farmers' coffee as a flavor experience. Through this, the country's coffee industry will improve its competitiveness and be in a better position to sustain its position in the in the growing global coffee markets. This study is relevant for sensory professionals and persons in the industry such as roasters, baristas, and product developers.

### **Acknowledgments**

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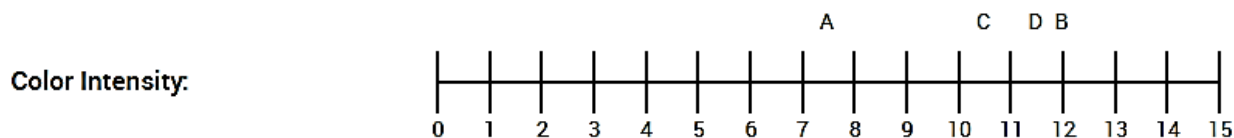
Standard Specification for Freezers, Ice Cream, Soft Serve, Shake BT - Standard Specification for Freezers, Ice Cream, Soft Serve, Shake. 15AD.

Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves BT - Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves. 17AD.

## Appendix A - The ballot for Cold Brew Sensory Evaluation

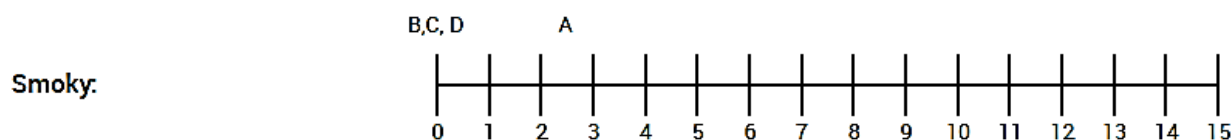
### APPEARANCE

**Color Intensity:** The intensity or strength of the white color from light to dark

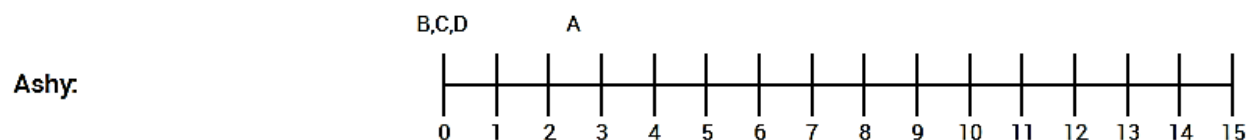


### AROMA

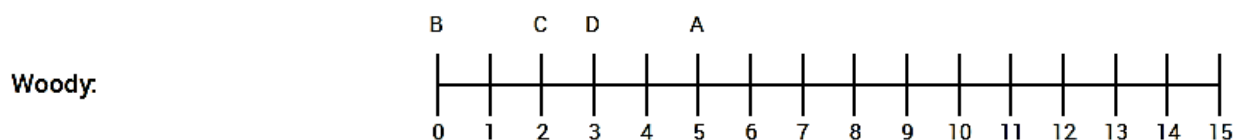
**Smoky:** An acute pungent aromatic that is a product of combustion of wood, leaves or non-natural product.



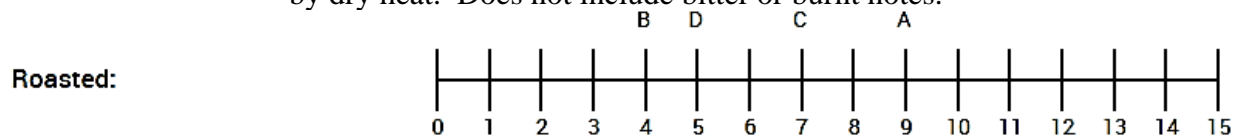
**Ashy:** Dry, dusty, dirty smoky aromatics associated with the residual of burnt products.



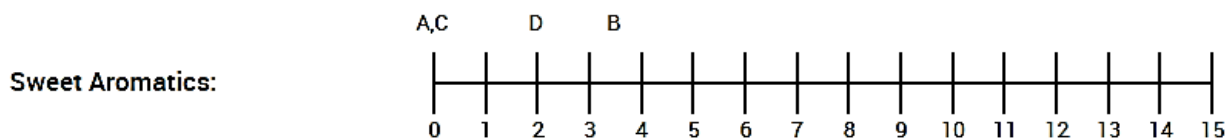
**Woody:** The sweet, brown, musty, dark aromatics associated with a bark of a tree.



**Roasted:** Brown impression characteristic of products cooked to a high temperature by dry heat. Does not include bitter or burnt notes.



**Sweet Aromatics:** An aromatic associated with the impression of a sweet substance.



**Burnt:** The dark brown impression of an over-cooked or over-roasted product that can be sharp, bitter and sour.



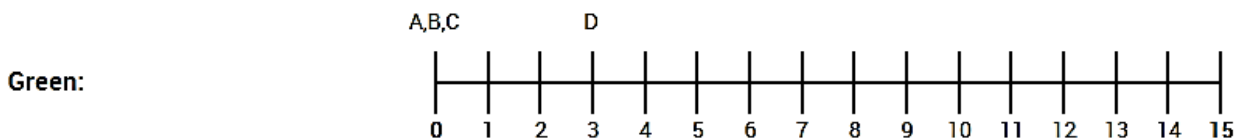
**Acrid:** The sharp pungent bitter acidic aromatics associated with products that are excessively roasted or browned.



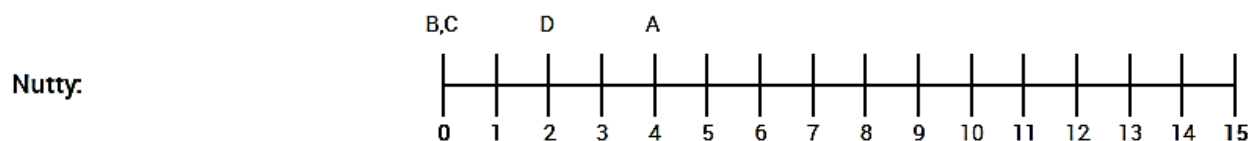
**Chocolate/Dark Chocolate:** A high-intensity blend of cocoa and cocoa butter that may include dark roast, spicy, burnt, must notes which includes increased astringency and bitterness.



**Green:** Aromatic characteristic of a fresh plant-based material. Attributes may include leafy, viney, unripe, grassy, peapod.



**Nutty:** A combination of slightly sweet, brown, woody, oily, musty, astringent, and bitter aromatics commonly associated with nuts, seeds, beans, and grains.



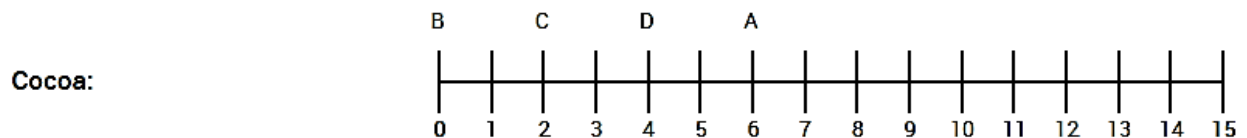
**Fruity:** A sweet, floral aromatic blend of a variety of ripe fruits.



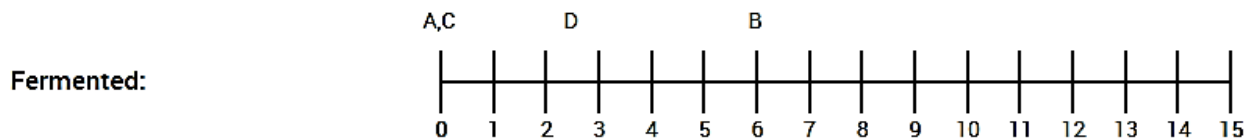
**Floral:** Sweet, light, slightly fragrant aromatic associated with (*fresh*) flowers.



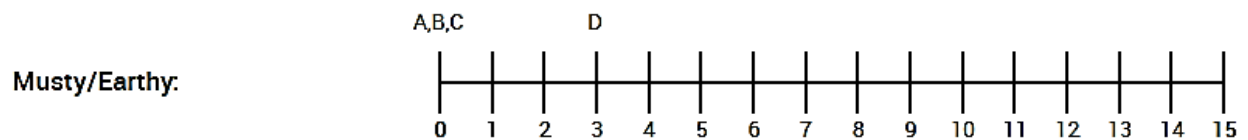
**Cocoa:** A brown, sweet, dusty, musty, often bitter aromatic associated with cocoa bean, powdered cocoa, and chocolate bars.



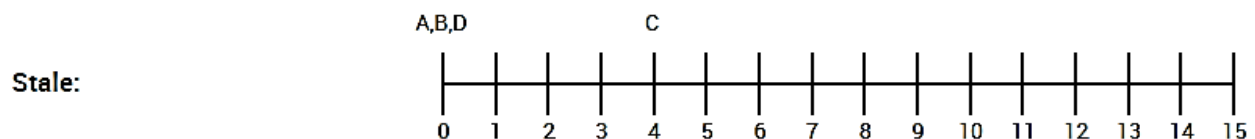
**Fermented:** Pungent, sweet, slightly sour, sometimes yeasty, alcohol like aromatics characteristics of fermented fruits or sugar or over-proofed dough



**Musty/Earthy:** The slightly musty aromatics associated with raw potatoes and damp humus, slightly musty notes.

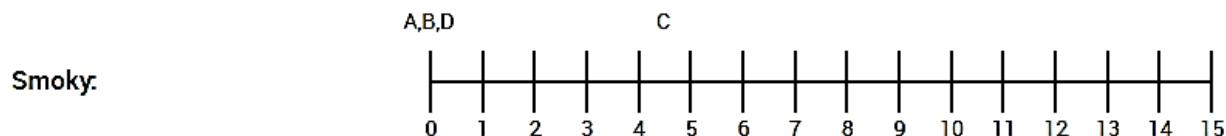


**Stale:** The aromatics characterized by lack of freshness

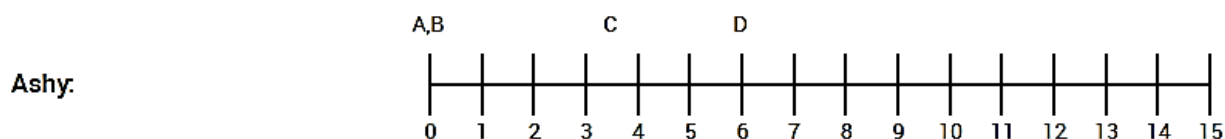


**FLAVOR**

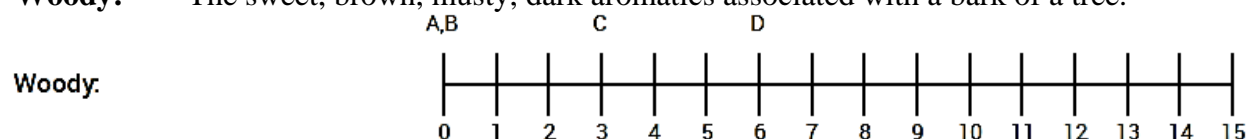
**Smoky:** An acute pungent aromatic that is a product of combustion of wood, leaves or non-natural product.



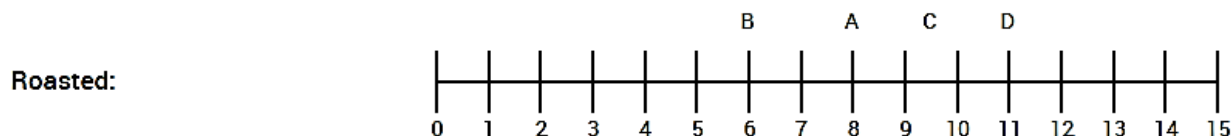
**Ashy:** Dry, dusty, dirty smoky aromatics associated with the residual of burnt products.



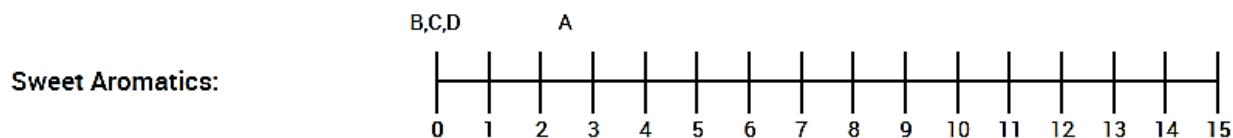
**Woody:** The sweet, brown, musty, dark aromatics associated with a bark of a tree.



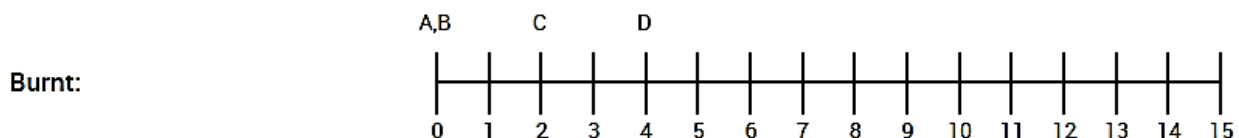
**Roasted:** Brown impression characteristic of products cooked to a high temperature by dry heat. Does not include bitter or burnt notes.



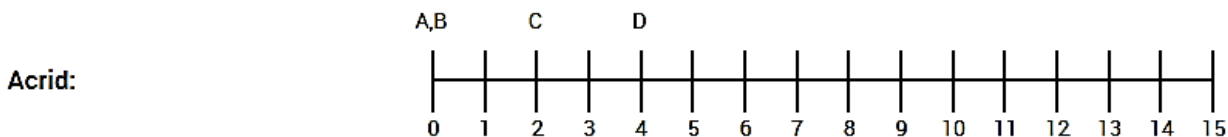
**Sweet Aromatics:** An aromatic associated with the impression of a sweet substance.



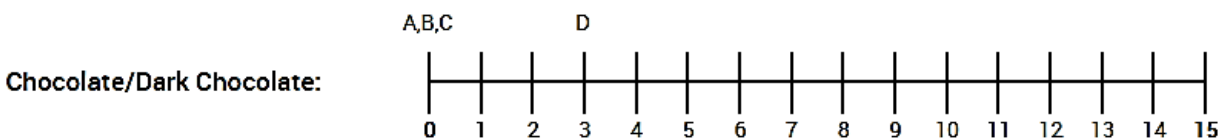
**Burnt:** The dark brown impression of an over-cooked or over-roasted product that can be sharp, bitter and sour.



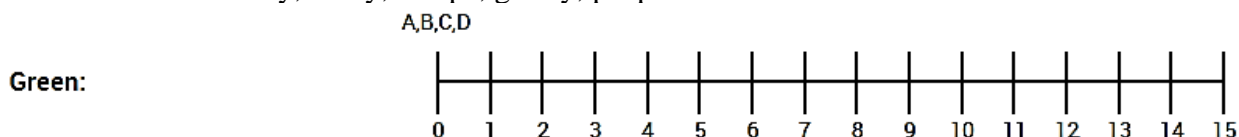
**Acrid:** The sharp pungent bitter acidic aromatics associated with products that are excessively roasted or browned.



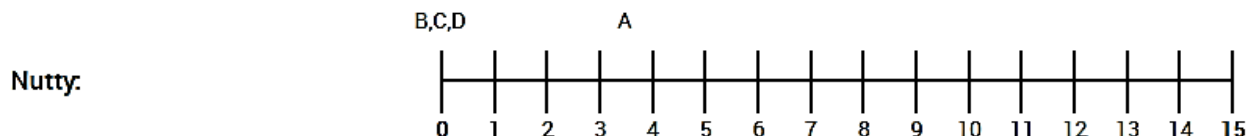
**Chocolate/Dark Chocolate:** A high-intensity blend of cocoa and cocoa butter that may include dark roast, spicy, burnt, must notes which includes increased astringency and bitterness.



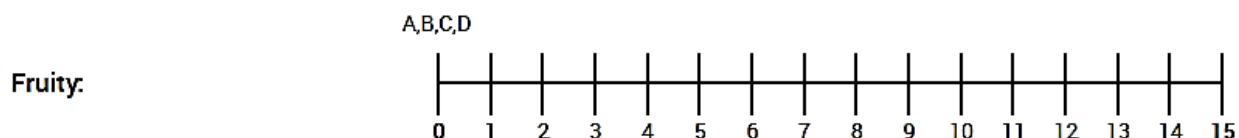
**Green:** Aromatic characteristic of a fresh plant-based material. Attributes may include leafy, viney, unripe, grassy, peapod.



**Nutty:** A combination of slightly sweet, brown, woody, oily, musty, astringent, and bitter aromatics commonly associated with nuts, seeds, beans, and grains.



**Fruity:** A sweet, floral aromatic blend of a variety of ripe fruits.

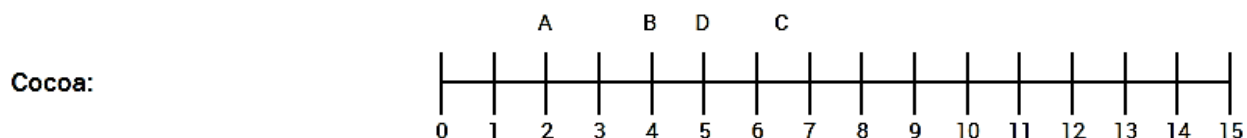


**Floral:** Sweet, light, slightly fragrant aromatic associated with (*fresh*) flowers.

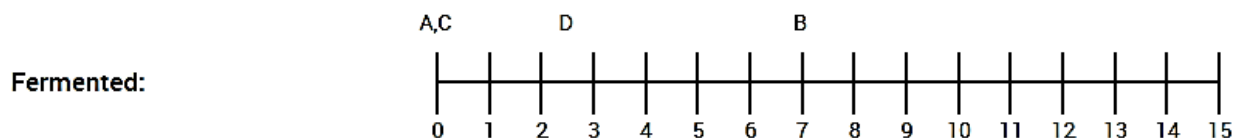


**Cocoa:** A brown, sweet, dusty, musty, often bitter aromatic associated with cocoa bean, powdered cocoa, and chocolate bars.

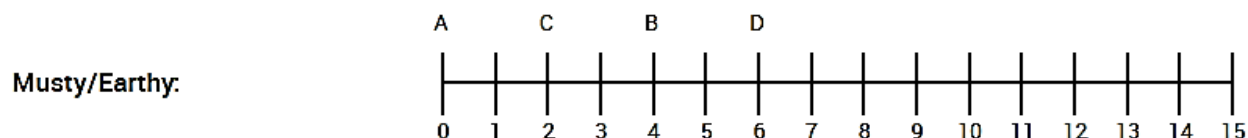




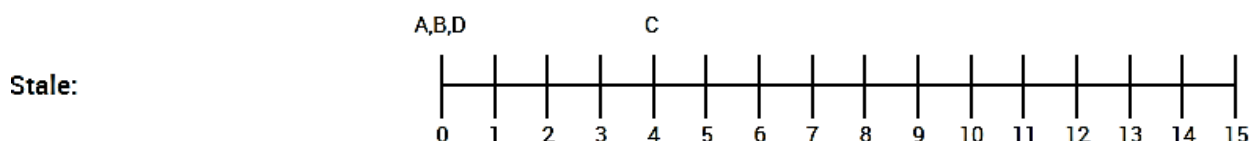
**Fermented:** Pungent, sweet, slightly sour, sometimes yeasty, alcohol like aromatics characteristics of fermented fruits or sugar or over-proofed dough



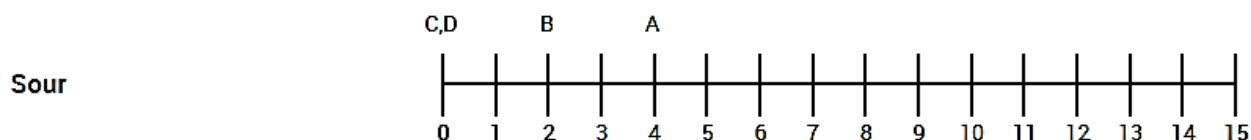
**Musty/Earthy:** The slightly musty aromatics associated with raw potatoes and damp humus, slightly musty notes.



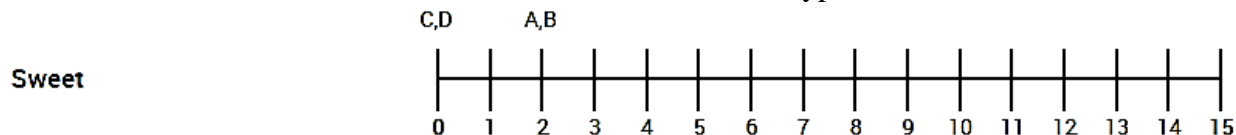
**Stale:** The aromatics characterized by lack of freshness



**Sour:** The fundamental taste factor associated with a citric acid solution.



**Sweet:** A fundamental taste factor of which sucrose is typical.



**Bitter:** The fundamental taste factor associated with a caffeine solution.



**Mouth Drying:** A drying puckering or tingling sensation on the surface and/or edge of the tongue and mouth.

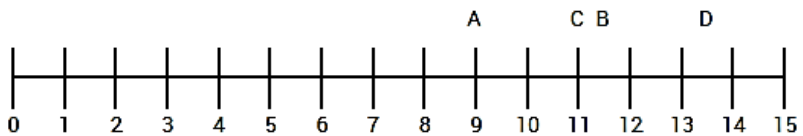
Mouth Drying:



## AFTERTASTE

**Bitter:** The fundamental taste factor associated with a caffeine solution.

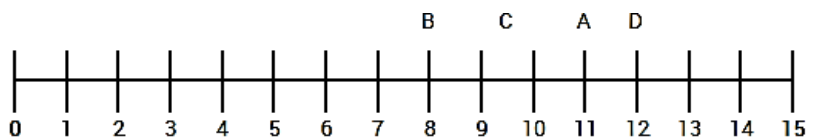
Bitter:



## AMPLITUDE

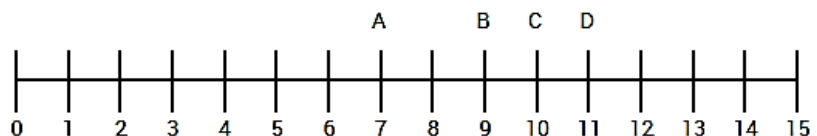
**Coffee ID (Fullness):** The foundation of flavors notes that gives substance to the product. The perception of a robust flavor that is rounded with the body; in this case a full, rounded coffee identity.

Coffee ID (Fullness):



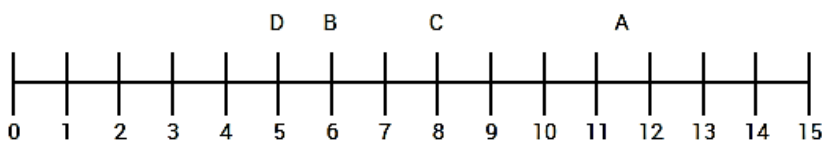
**Overall impact:** The maximum overall sensory impression during the whole tasting time.

Overall impact:



**Balance/Blended:** The melding of individual sensory notes such that the products present a unified overall sensory experience as opposed to spikes or individual notes.

Balance/Blended:



**Longevity:** The time that the full integrated sensory experience sustain itself in the month and after swallowing

Longevity:



## Appendix B - SAS codes for Descriptive Analysis of Samples

```
dm'log;clear;output;clear;';
Data (data name);
input sample$ roast$ c2wr$ bmethod$ rep$ panelist$ attr1 attr2 attr3 attr4 attr5 attr6 attr7 attr8
attr9 attr10 attr11 attr12 attr13 attr14 attr15 attr16 attr17 attr18 attr19 attr20 attr21 attr22 attr23
attr24 attr25 attr26 attr27 attr28 attr29 attr30 attr31 attr32 attr33 attr34 attr35 attr36 attr37 attr38
attr39 attr40 attr41 attr42
datalines;
(input raw data here);
ods rtf;
proc means;
by sample;
var attr1-attr42;
run;
proc glimmix;
class sample rep panelist roast c2wr bmethod;
model attr# = sample roast c2wr bmethod sample*roast sample*c2wr sample*bmethod
roast*c2wr roast*bmethod c2wr*bmethod sample*roast*c2wr sample*roast*bmethod
roast*c2wr*bmethod sample*roast*c2wr*bmethod/ddfm=sat;
random rep panelist;
lsmeans sample roast c2wr bmethod sample*roast sample*c2wr sample*bmethod roast*c2wr
roast*bmethod c2wr*bmethod sample*roast*c2wr sample*roast*bmethod roast*c2wr*bmethod
sample*roast*c2wr*bmethod/pdiff lines;
run;

ods rtf close; quit;
```

### Notes:

1. In the Proc statement;
  - attr1 corresponds to the first attributed listed and attr 42 corresponds to the last attribute listed
  - roast corresponds to the degree of roasting
  - c2wr corresponds to the coffee to water ratio
  - bmethod corresponds to brewing method
2. The Proc Glimmix procedure is repeated for all the attributes

## Appendix C - ANOVA Table Scores for main effects

Table C-1 ANOVA Table Scores for main effects

Sample	Color Identity	Smoky(a)	Ashy(a)	Woody(a)	Roasted(a)	Sweet aromatics(a)	Burnt(a)	Acrid(a)
AW	7.85 <sup>b</sup>	1.18 <sup>b</sup>	0.43 <sup>b</sup>	2.07 <sup>c</sup>	6.51 <sup>b</sup>	2.55 <sup>bc</sup>	0.07 <sup>ab</sup>	0.12
AD	7.97 <sup>b</sup>	0.39 <sup>c</sup>	0.21 <sup>c</sup>	2.09 <sup>c</sup>	5.82 <sup>c</sup>	3.02 <sup>a</sup>	0.00 <sup>b</sup>	0.03
RW	8.28 <sup>a</sup>	1.52 <sup>a</sup>	0.68 <sup>a</sup>	2.70 <sup>a</sup>	7.10 <sup>a</sup>	2.38 <sup>c</sup>	0.11 <sup>a</sup>	0.03
RD	8.43 <sup>a</sup>	1.13 <sup>b</sup>	0.48 <sup>ab</sup>	2.38 <sup>b</sup>	6.53 <sup>b</sup>	2.67 <sup>b</sup>	0.00 <sup>b</sup>	0.07
<b>Roast</b>								
Dark	7.91 <sup>b</sup>	1.1	0.39	2.31	6.5	2.75 <sup>a</sup>	0.03	0.06
Medium	8.35 <sup>a</sup>	1	0.51	2.31	6.49	2.55 <sup>b</sup>	0.06	0.07
<b>C2WR</b>								
c2wr12	8.79 <sup>a</sup>	0.98	0.4	2.23	6.68 <sup>a</sup>	2.73 <sup>a</sup>	0.02	0.07
c2wr8	7.47 <sup>b</sup>	1.13	0.5	2.39	6.30 <sup>b</sup>	2.57 <sup>b</sup>	0.07	0.06
<b>Brew Method</b>								
Drip	8.94 <sup>a</sup>	1.16 <sup>a</sup>	0.48	2.46 <sup>a</sup>	6.74 <sup>a</sup>	2.82 <sup>a</sup>	0.05	0.08
Steep	7.32 <sup>b</sup>	0.94 <sup>b</sup>	0.42	2.16 <sup>b</sup>	6.24 <sup>b</sup>	2.49 <sup>b</sup>	0.04	0.04

**Table C 1 ANOVA Table Scores for main effects (continued)**

<b>Sample</b>	<b>Chocolate/Dark Chocolate(a)</b>	<b>Green(a)</b>	<b>Nutty(a)</b>	<b>Fruity(a)</b>	<b>Floral(a)</b>	<b>Cocoa(a)</b>	<b>Fermented(a)</b>	<b>Musty/Earthy(a)</b>
AW	1.29 <sup>b</sup>	0.85 <sup>b</sup>	2.83 <sup>a</sup>	2.54 <sup>b</sup>	1.42 <sup>b</sup>	2.61 <sup>a</sup>	3.50 <sup>c</sup>	0.15 <sup>b</sup>
AD	1.35 <sup>b</sup>	1.61 <sup>a</sup>	2.52 <sup>b</sup>	3.48 <sup>a</sup>	2.09 <sup>a</sup>	2.38 <sup>b</sup>	4.88 <sup>a</sup>	0.53 <sup>a</sup>
RW	1.95 <sup>a</sup>	0.74 <sup>b</sup>	2.28 <sup>c</sup>	1.93 <sup>c</sup>	1.07 <sup>c</sup>	2.59 <sup>ab</sup>	2.98 <sup>d</sup>	0.45 <sup>a</sup>
RD	1.71 <sup>a</sup>	0.91 <sup>b</sup>	2.29 <sup>c</sup>	2.54 <sup>b</sup>	1.46 <sup>b</sup>	2.50 <sup>ab</sup>	3.94 <sup>b</sup>	0.42 <sup>a</sup>
<b>Roast</b>								
Dark	1.43 <sup>b</sup>	0.96	2.46	2.59	1.61 <sup>a</sup>	2.43 <sup>b</sup>	4.02 <sup>a</sup>	0.37
Medium	1.72 <sup>a</sup>	1.1	2.5	2.65	1.40 <sup>b</sup>	2.61 <sup>a</sup>	3.62 <sup>b</sup>	0.41
<b>C2WR</b>								
c2wr12	1.70 <sup>a</sup>	1.03	2.47	2.82 <sup>a</sup>	1.73 <sup>a</sup>	2.63 <sup>a</sup>	4.07 <sup>a</sup>	0.45
c2wr8	1.45 <sup>b</sup>	1.02	2.49	2.43 <sup>b</sup>	1.29 <sup>b</sup>	2.41 <sup>b</sup>	3.58 <sup>b</sup>	0.32
<b>Brew Method</b>								
Drip	1.86 <sup>a</sup>	0.69 <sup>b</sup>	2.48	2.79 <sup>a</sup>	1.6 <sup>a</sup>	2.66 <sup>a</sup>	3.95 <sup>a</sup>	0.29 <sup>b</sup>
Steep	1.29 <sup>b</sup>	1.37 <sup>a</sup>	2.47	2.46 <sup>b</sup>	1.42 <sup>b</sup>	2.38 <sup>b</sup>	3.70 <sup>b</sup>	0.49 <sup>a</sup>

**Table C 1 ANOVA Table Scores for main effects (continued)**

<b>Sample</b>	<b>Stale(a)</b>	<b>Smoky(f)</b>	<b>Ashy(f)</b>	<b>Woody(f)</b>	<b>Roasted(f)</b>	<b>Sweet Aroma(f)</b>	<b>Burnt(f)</b>	<b>Acrid(f)</b>
AW	0.17 <sup>ab</sup>	1.52 <sup>c</sup>	1.41 <sup>b</sup>	2.95 <sup>c</sup>	7.83 <sup>c</sup>	1.54 <sup>a</sup>	0.73 <sup>c</sup>	1.30 <sup>c</sup>
AD	0.28 <sup>ab</sup>	1.45 <sup>c</sup>	1.47 <sup>b</sup>	3.04 <sup>c</sup>	7.89 <sup>c</sup>	1.58 <sup>a</sup>	0.78 <sup>c</sup>	1.35 <sup>c</sup>
RW	0.16 <sup>b</sup>	2.4 <sup>a</sup>	2.40 <sup>a</sup>	3.63 <sup>a</sup>	9.00 <sup>a</sup>	0.40 <sup>c</sup>	1.92 <sup>a</sup>	2.35 <sup>a</sup>
RD	0.33 <sup>a</sup>	2.09 <sup>b</sup>	2.27 <sup>a</sup>	3.40 <sup>b</sup>	8.74 <sup>b</sup>	0.93 <sup>b</sup>	1.57 <sup>b</sup>	2.03 <sup>b</sup>
<b>Roast</b>								
Dark	0.21	2.11 <sup>a</sup>	2.12 <sup>a</sup>	3.42 <sup>a</sup>	8.68 <sup>a</sup>	0.94 <sup>b</sup>	1.38 <sup>a</sup>	2.10 <sup>a</sup>
Medium	0.26	1.63 <sup>b</sup>	1.65 <sup>b</sup>	3.09 <sup>b</sup>	8.05 <sup>b</sup>	1.29 <sup>a</sup>	1.12 <sup>b</sup>	1.42 <sup>b</sup>
<b>C2WR</b>								
c2wr12	0.22	2.07 <sup>a</sup>	2.23 <sup>a</sup>	3.38 <sup>a</sup>	8.79 <sup>a</sup>	0.91 <sup>b</sup>	1.53 <sup>a</sup>	2.11 <sup>a</sup>
c2wr8	0.25	1.67 <sup>b</sup>	1.55 <sup>b</sup>	3.13 <sup>b</sup>	7.94 <sup>b</sup>	1.31 <sup>a</sup>	0.97 <sup>b</sup>	1.40 <sup>b</sup>
<b>Brew Method</b>								
Drip	0.14 <sup>b</sup>	2.05 <sup>a</sup>	2.15 <sup>a</sup>	3.49 <sup>a</sup>	8.94 <sup>a</sup>	1.00 <sup>b</sup>	1.43 <sup>a</sup>	2.06 <sup>a</sup>
Steep	0.33 <sup>a</sup>	1.68 <sup>b</sup>	1.62 <sup>b</sup>	3.02 <sup>b</sup>	7.79 <sup>b</sup>	1.22 <sup>a</sup>	1.07 <sup>b</sup>	1.46 <sup>b</sup>

**Table C 1 ANOVA Table Scores for main effects (continued)**

<b>Sample</b>	<b>Chocolate/Dark Chocolate(f)</b>	<b>Green(f)</b>	<b>Nutty(f)</b>	<b>Fruity(f)</b>	<b>Floral(f)</b>	<b>Cocoa(f)</b>	<b>Fermented(f)</b>	<b>Musty/Earthy(f)</b>
AW	2.08 <sup>b</sup>	1.00 <sup>a</sup>	1.95 <sup>a</sup>	2.23 <sup>b</sup>	1.06 <sup>a</sup>	2.94 <sup>ab</sup>	3.45 <sup>b</sup>	1.23 <sup>b</sup>
AD	2.43 <sup>a</sup>	1.09 <sup>a</sup>	1.58 <sup>b</sup>	2.53 <sup>a</sup>	1.05 <sup>a</sup>	2.88 <sup>b</sup>	4.37 <sup>a</sup>	1.27 <sup>b</sup>
RW	2.57 <sup>a</sup>	0.05 <sup>c</sup>	0.95 <sup>c</sup>	0.88 <sup>d</sup>	0.34 <sup>b</sup>	3.10 <sup>a</sup>	2.49 <sup>d</sup>	2.09 <sup>a</sup>
RD	2.51 <sup>a</sup>	0.53 <sup>b</sup>	1.33 <sup>b</sup>	1.14 <sup>c</sup>	0.32 <sup>b</sup>	3.13 <sup>a</sup>	2.95 <sup>c</sup>	2.23 <sup>a</sup>
<b>Roast</b>								
Dark	2.48	0.49 <sup>b</sup>	1.26 <sup>b</sup>	1.59 <sup>b</sup>	0.78 <sup>a</sup>	3	3.39	1.69
Medium	2.31	0.84 <sup>a</sup>	1.65 <sup>a</sup>	1.79 <sup>a</sup>	0.61 <sup>b</sup>	3.02	3.24	1.71
<b>C2WR</b>								
c2wr12	2.59 <sup>a</sup>	0.67	1.35 <sup>b</sup>	1.74	0.64	2.96	3.54 <sup>a</sup>	1.90 <sup>a</sup>
c2wr8	2.20 <sup>b</sup>	0.67	1.55 <sup>a</sup>	1.64	0.75	3.07	3.09 <sup>b</sup>	1.51 <sup>b</sup>
<b>Brew Method</b>								
Drip	2.71 <sup>a</sup>	0.45 <sup>b</sup>	1.39	1.82 <sup>a</sup>	0.86 <sup>a</sup>	3.08	3.57 <sup>a</sup>	1.89 <sup>a</sup>
Steep	2.08 <sup>b</sup>	0.89 <sup>a</sup>	1.52	1.56 <sup>b</sup>	0.82 <sup>b</sup>	2.95	3.06 <sup>b</sup>	1.52 <sup>b</sup>



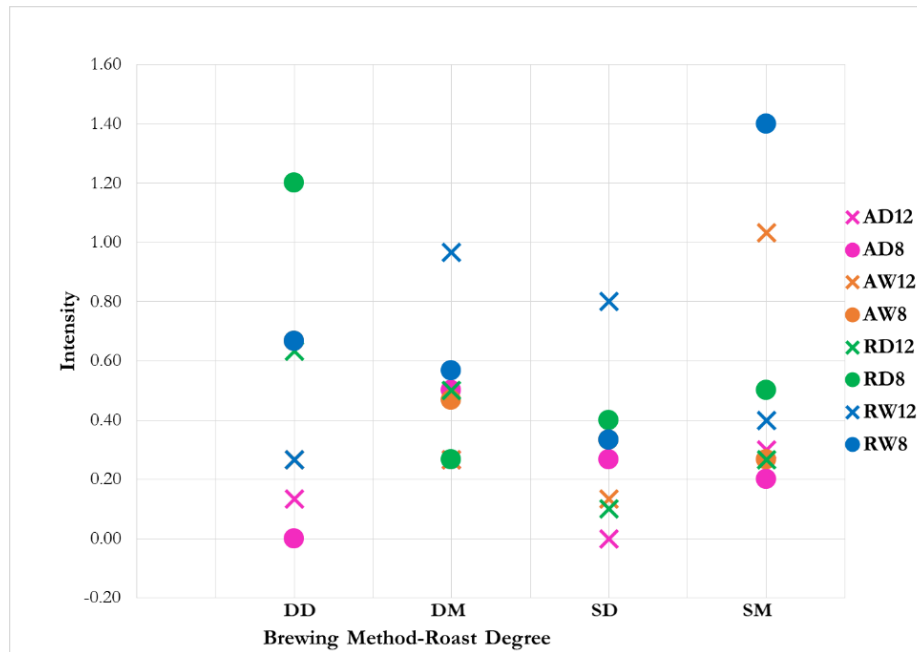
**Table C 1 ANOVA Table Scores for main effects (continued)**

<b>Sample</b>	<b>Stale(f)</b>	<b>Sour(f)</b>	<b>Sweet(f)</b>	<b>Bitter(f)</b>	<b>Mouthfeel(f)</b>	<b>Bitter(at)</b>	<b>Coffee ID</b>	<b>Overall Impact</b>
AW	0.48 <sup>c</sup>	1.92 <sup>a</sup>	0.80 <sup>b</sup>	9.36 <sup>b</sup>	2.18 <sup>b</sup>	9.65 <sup>b</sup>	9.38 <sup>c</sup>	8.31 <sup>d</sup>
AD	0.71b <sup>c</sup>	1.85 <sup>a</sup>	1.20 <sup>a</sup>	9.24 <sup>b</sup>	2.19 <sup>b</sup>	9.50 <sup>b</sup>	9.35 <sup>c</sup>	8.75 <sup>c</sup>
RW	0.84 <sup>ab</sup>	1.41 <sup>b</sup>	0.12 <sup>d</sup>	10.28 <sup>a</sup>	2.28 <sup>a</sup>	10.66 <sup>a</sup>	10.39 <sup>a</sup>	9.90 <sup>a</sup>
RD	0.99 <sup>a</sup>	1.69 <sup>a</sup>	0.33 <sup>c</sup>	10.08 <sup>a</sup>	2.28 <sup>a</sup>	10.41 <sup>a</sup>	10.03 <sup>b</sup>	9.47 <sup>b</sup>
<b>Roast</b>								
Dark	0.68	1.78	0.48 <sup>b</sup>	9.97 <sup>a</sup>	2.25	10.32 <sup>a</sup>	10.11 <sup>a</sup>	9.47 <sup>a</sup>
Medium	0.83	1.65	0.75 <sup>a</sup>	9.51 <sup>b</sup>	2.21	9.79 <sup>b</sup>	9.47 <sup>b</sup>	8.74 <sup>b</sup>
<b>C2WR</b>								
c2wr12	0.77	1.83 <sup>a</sup>	0.50 <sup>b</sup>	10.23 <sup>a</sup>	2.29 <sup>a</sup>	10.51 <sup>a</sup>	10.34 <sup>a</sup>	9.87 <sup>a</sup>
c2wr8	0.74	1.61 <sup>b</sup>	0.72 <sup>a</sup>	9.25 <sup>b</sup>	2.18 <sup>b</sup>	9.60 <sup>b</sup>	9.23 <sup>b</sup>	8.34 <sup>b</sup>
<b>Brew Method</b>								
Drip	0.77	1.56 <sup>b</sup>	0.54	9.97 <sup>a</sup>	2.29 <sup>a</sup>	10.34 <sup>a</sup>	10.36 <sup>a</sup>	9.55 <sup>a</sup>
Steep	0.74	1.87 <sup>a</sup>	0.68	9.51 <sup>b</sup>	2.18 <sup>b</sup>	9.78 <sup>b</sup>	9.22 <sup>b</sup>	8.66 <sup>b</sup>

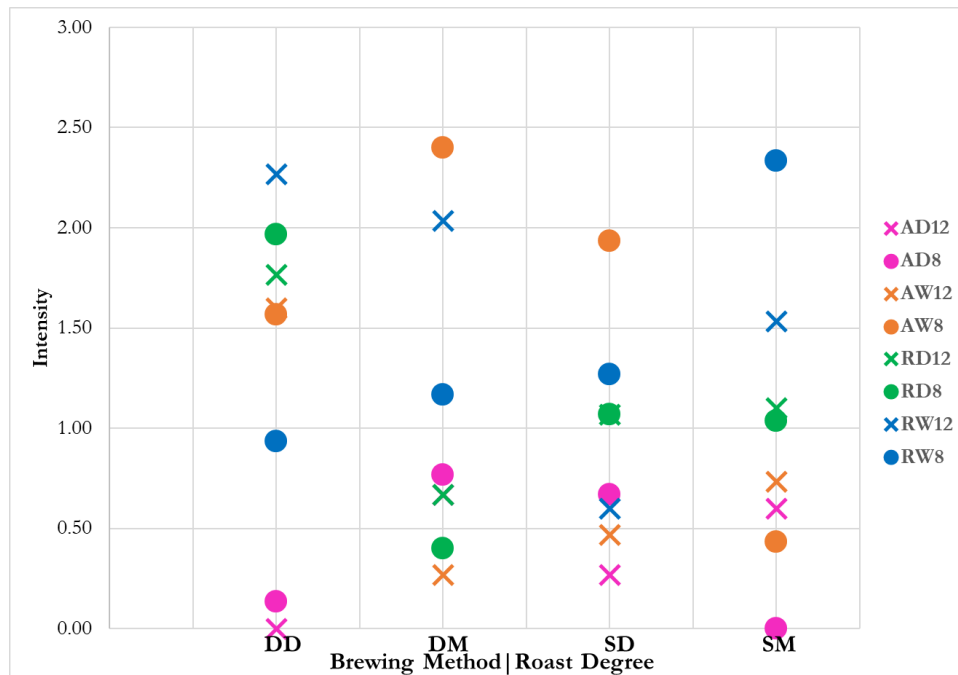
**Table C 1 ANOVA Table Scores for main effects (continued)**

<b>Sample</b>	<b>Balance/Blended</b>	<b>Longevity</b>
AW	9.46 <sup>a</sup>	8.54 <sup>c</sup>
AD	9.29 <sup>a</sup>	8.55 <sup>c</sup>
RW	7.79 <sup>c</sup>	9.32 <sup>b</sup>
RD	8.36 <sup>b</sup>	10.16 <sup>a</sup>
<b>Roast</b>		
Dark	8.10 <sup>b</sup>	9.73 <sup>a</sup>
Medium	9.35 <sup>a</sup>	8.56 <sup>b</sup>
<b>C2WR</b>		
c2wr12	8.28 <sup>b</sup>	9.83 <sup>a</sup>
c2wr8	9.17 <sup>a</sup>	8.45 <sup>b</sup>
<b>Brew Method</b>		
Drip	8.50 <sup>b</sup>	9.69 <sup>a</sup>
Steep	8.95 <sup>a</sup>	8.60 <sup>b</sup>

## Appendix D - Statistically Significant Interactions

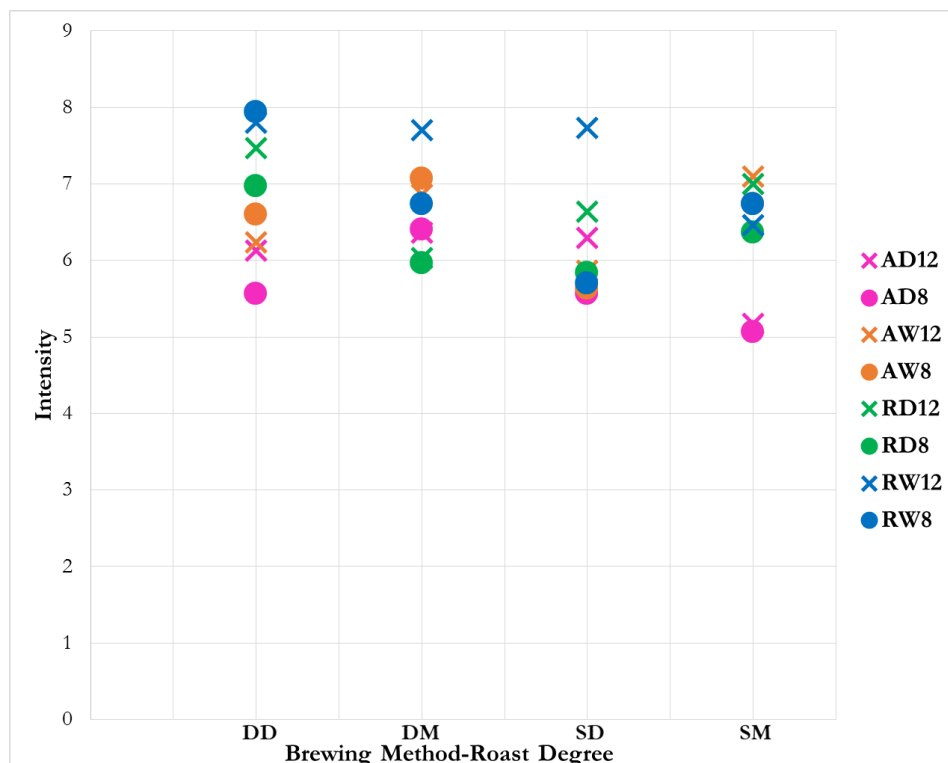


**Figure D-1 Four-way interaction for Ashy aroma**

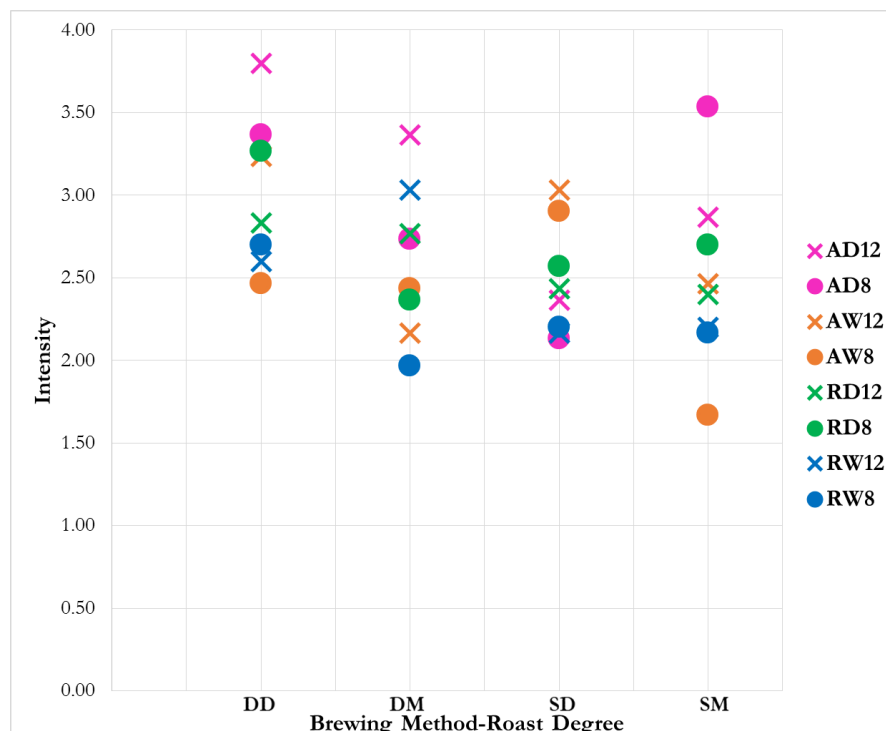


**Figure D-2 Four-way interaction for Smoky aroma**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)

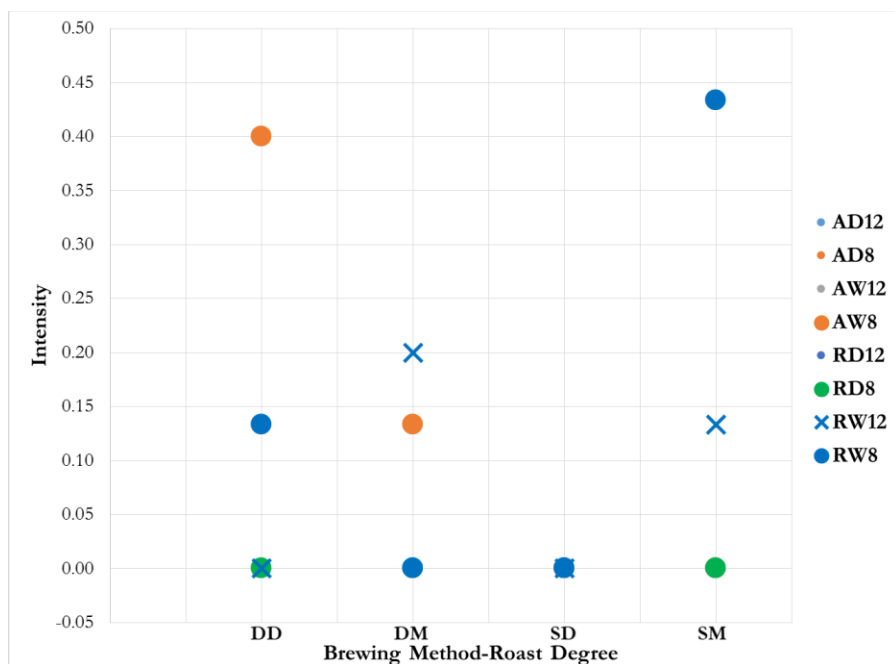


**Figure D-3 Four-way interaction for Roasted aroma**

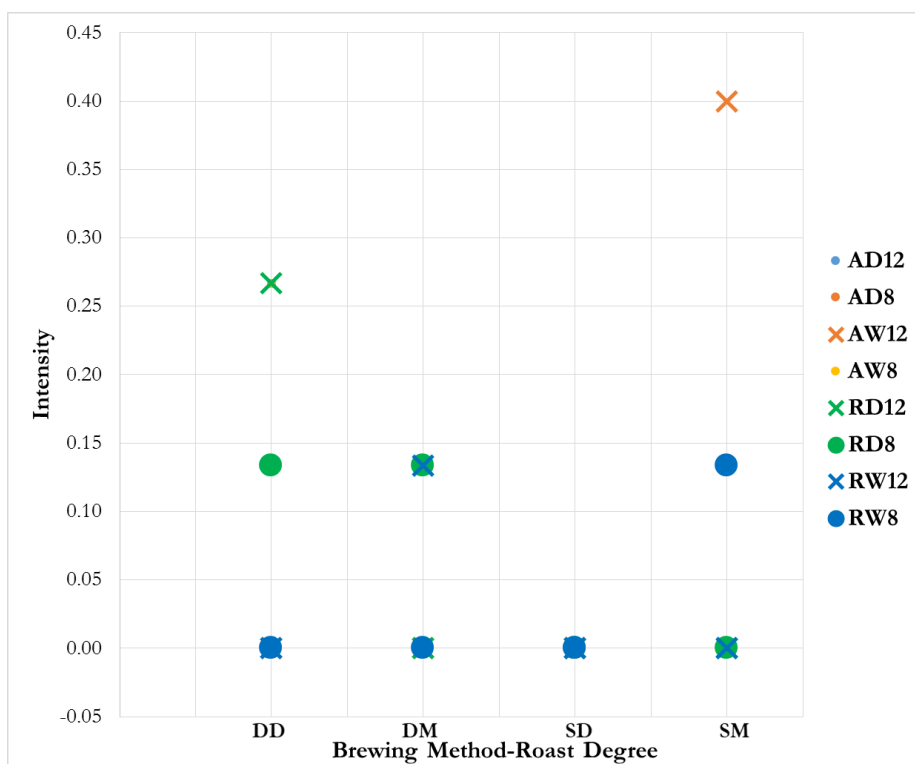


**Figure D-4 Four-way interaction for Sweet Aromatics aroma**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)

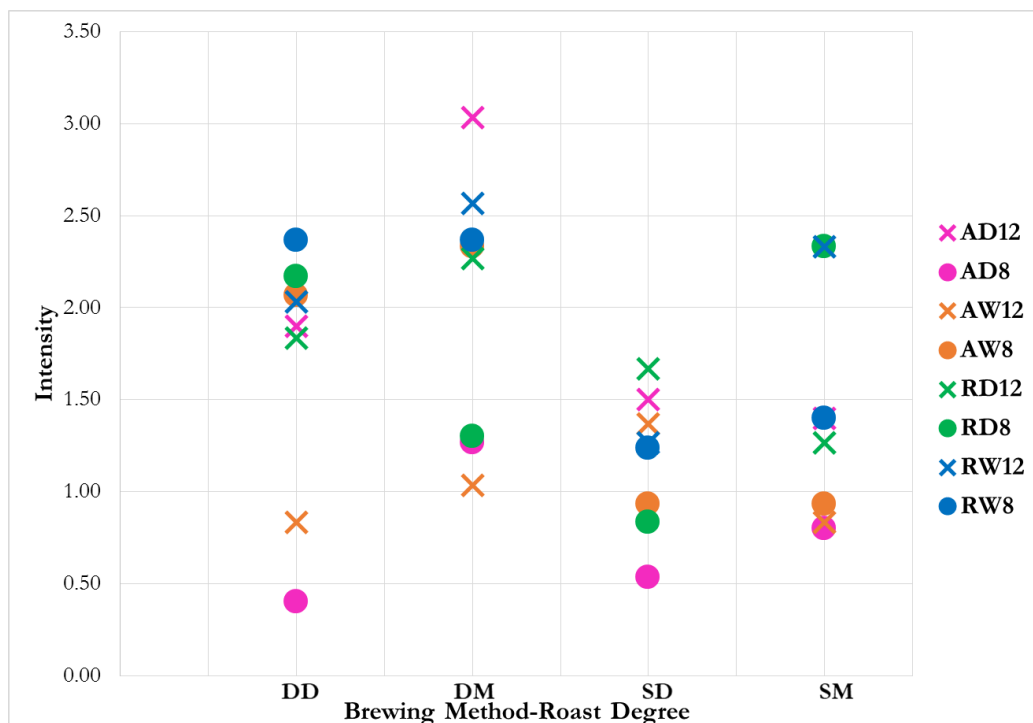


**Figure D-5 Four-way interaction for Burnt aroma**

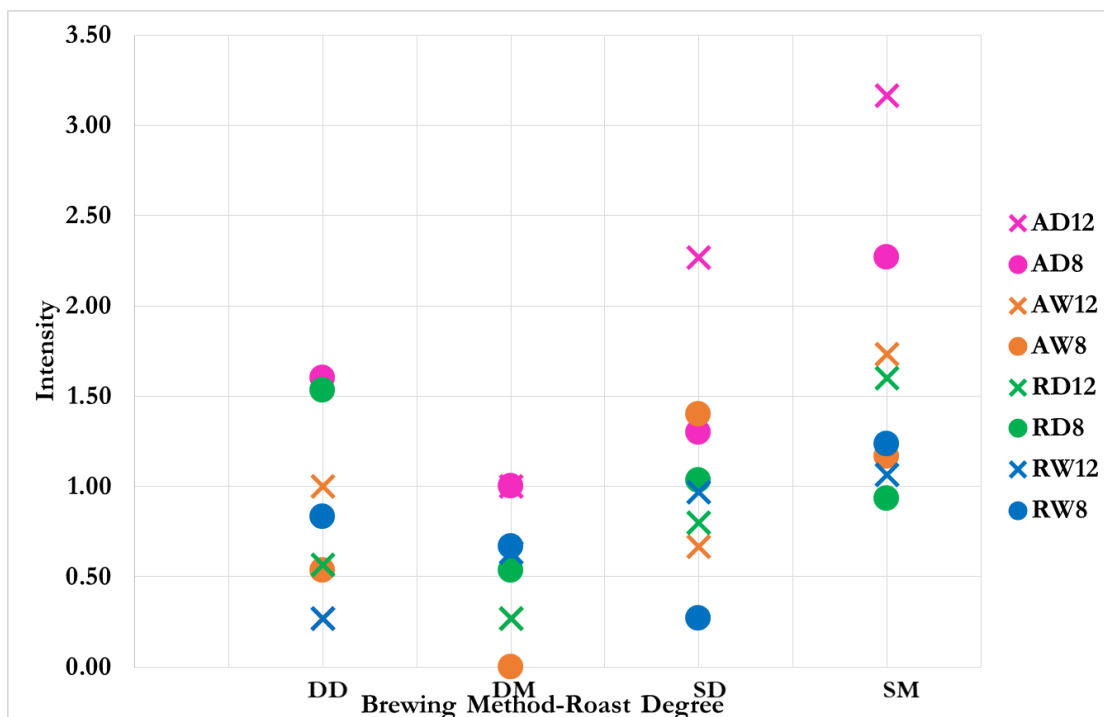


**Figure D-6 Four-way interaction for Acrid aroma**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)

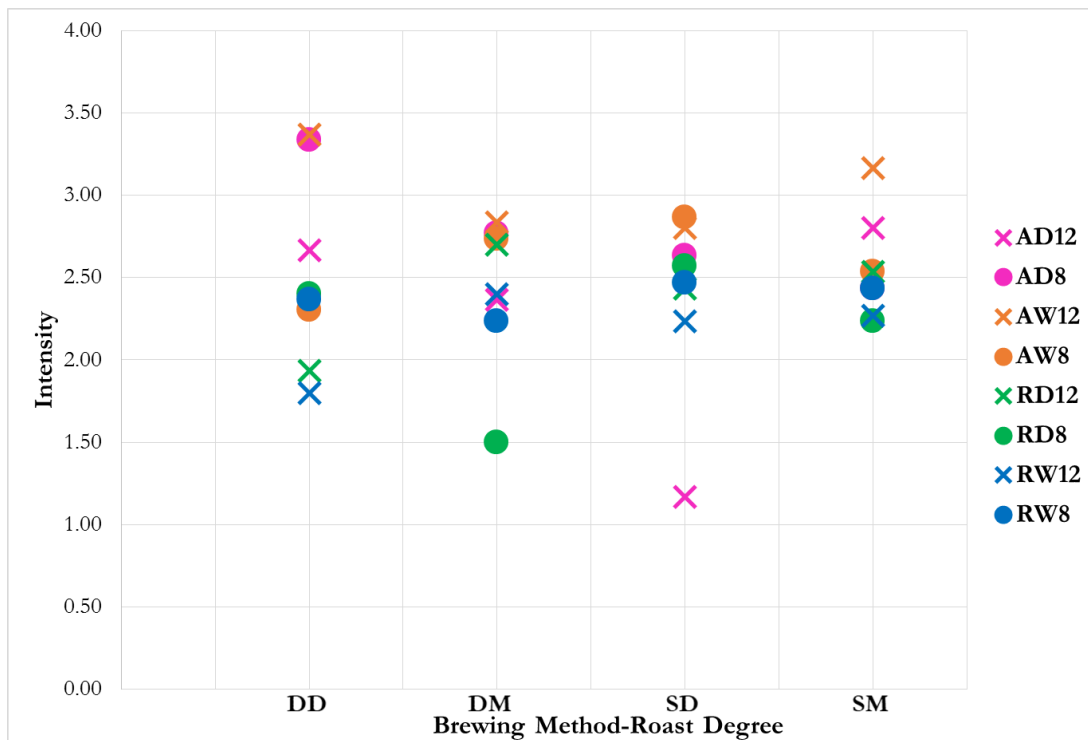


**Figure D-7 Four-way interaction for Chocolate/Dark Chocolate aroma**

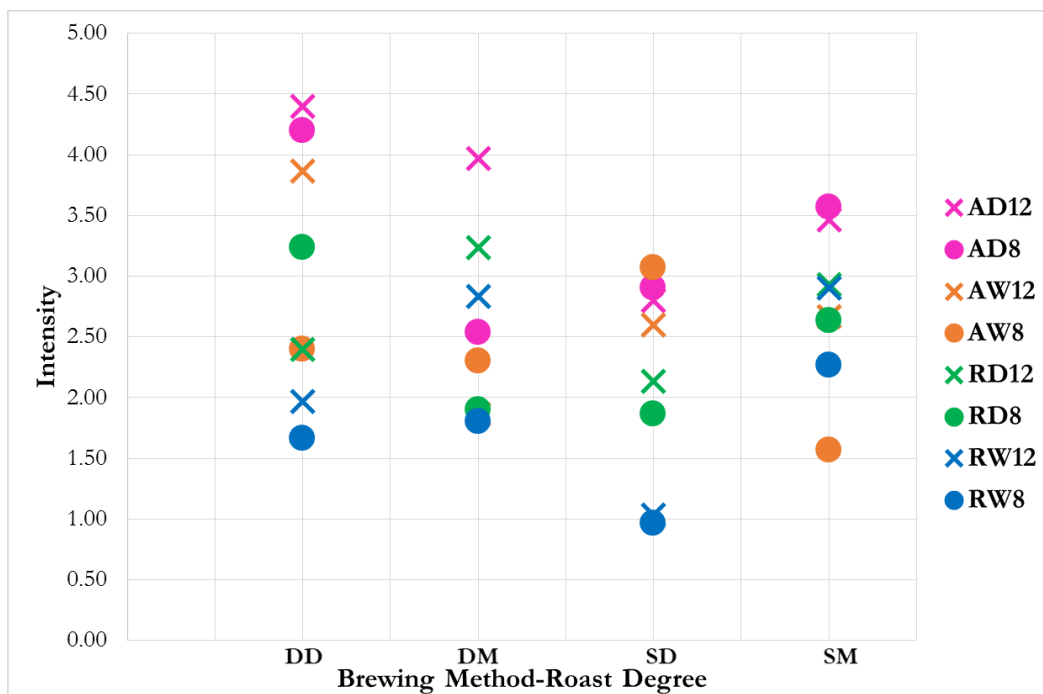


**Figure D-8 Four-way interaction for Green aroma**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)

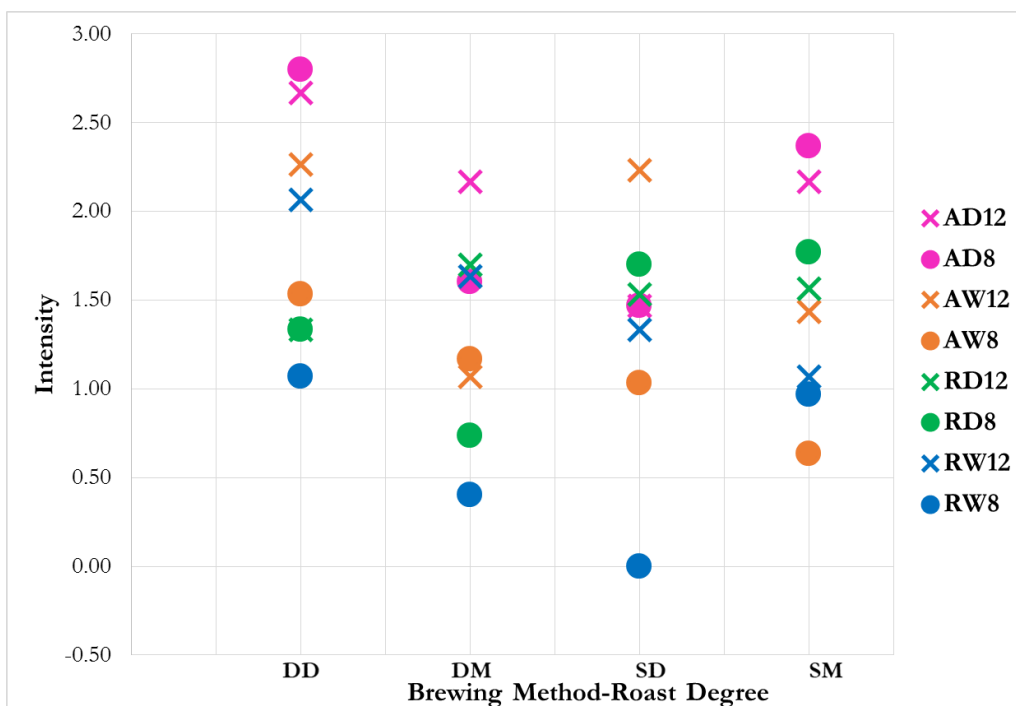


**Figure D-9 Four-way interaction for Nutty aroma**

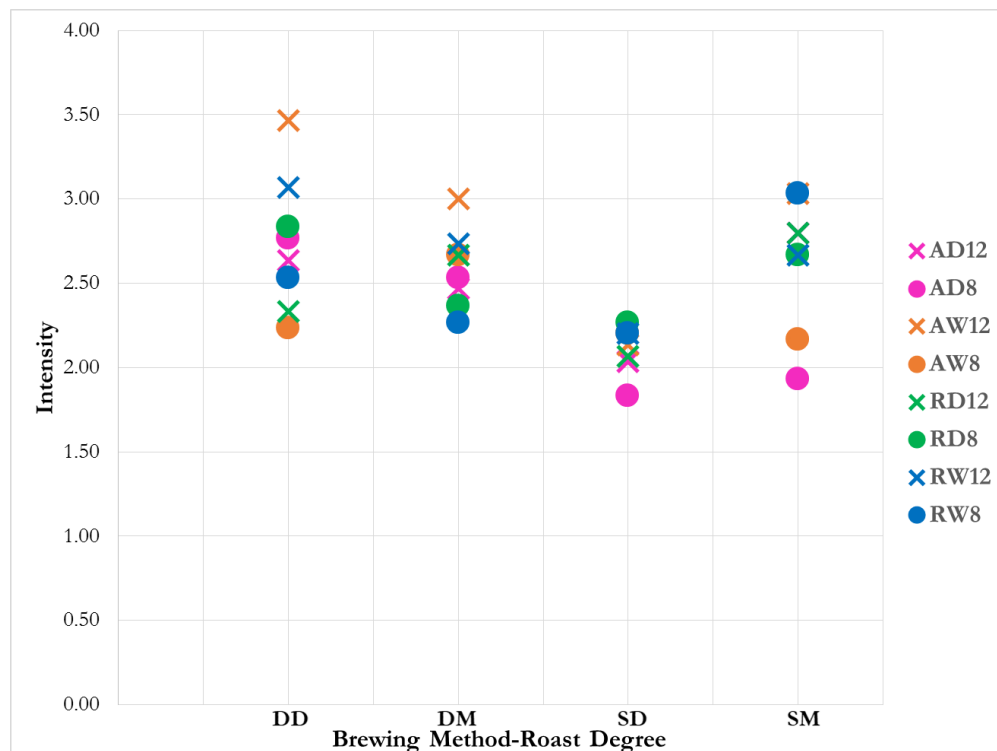


**Figure D-10 Four-way interaction for Fruity aroma**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)



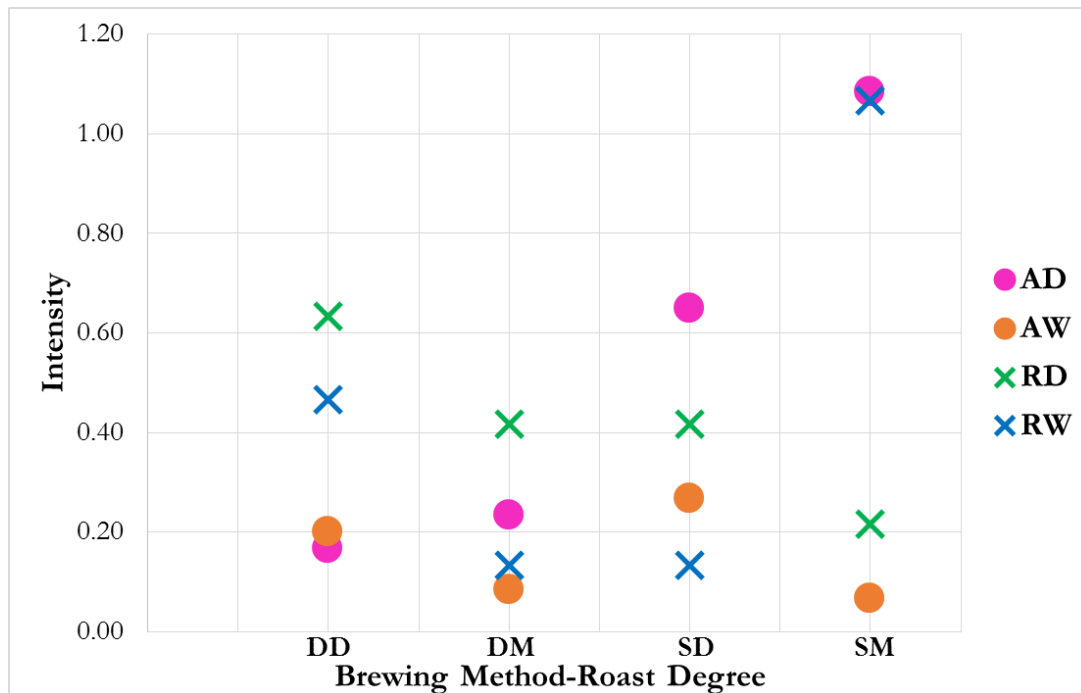
**Figure D-11 Four-way interaction for Floral aroma**



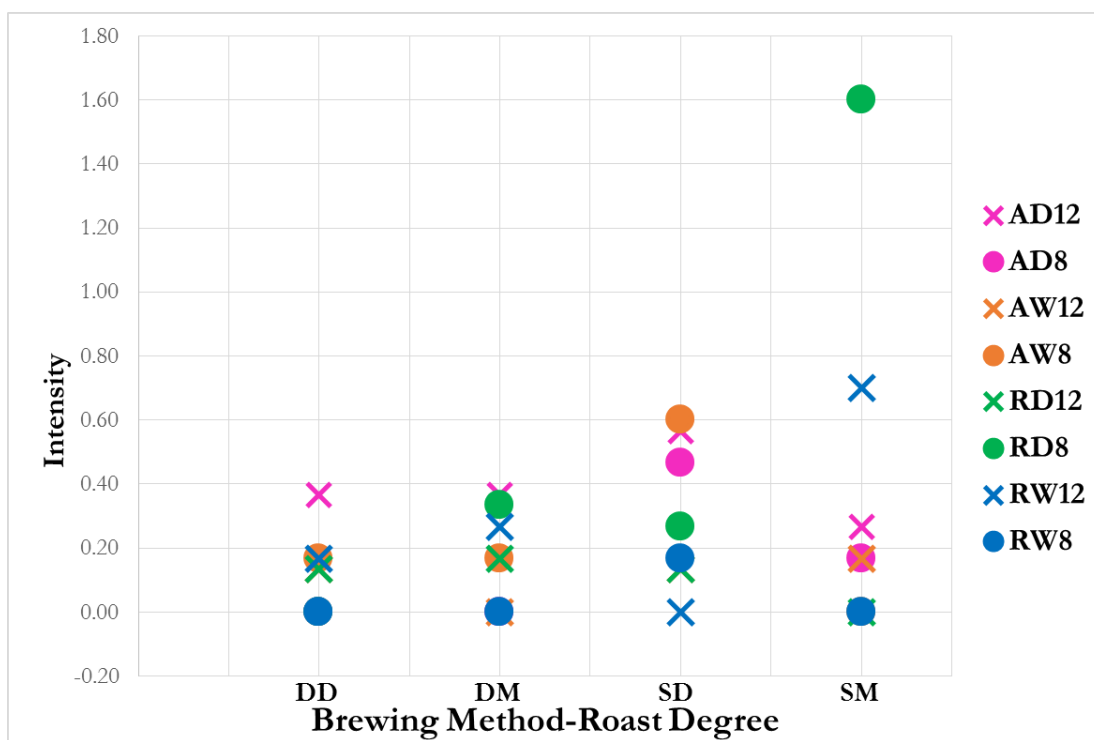
**Figure D-12 Four-way interaction for Cocoa aroma**



(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)

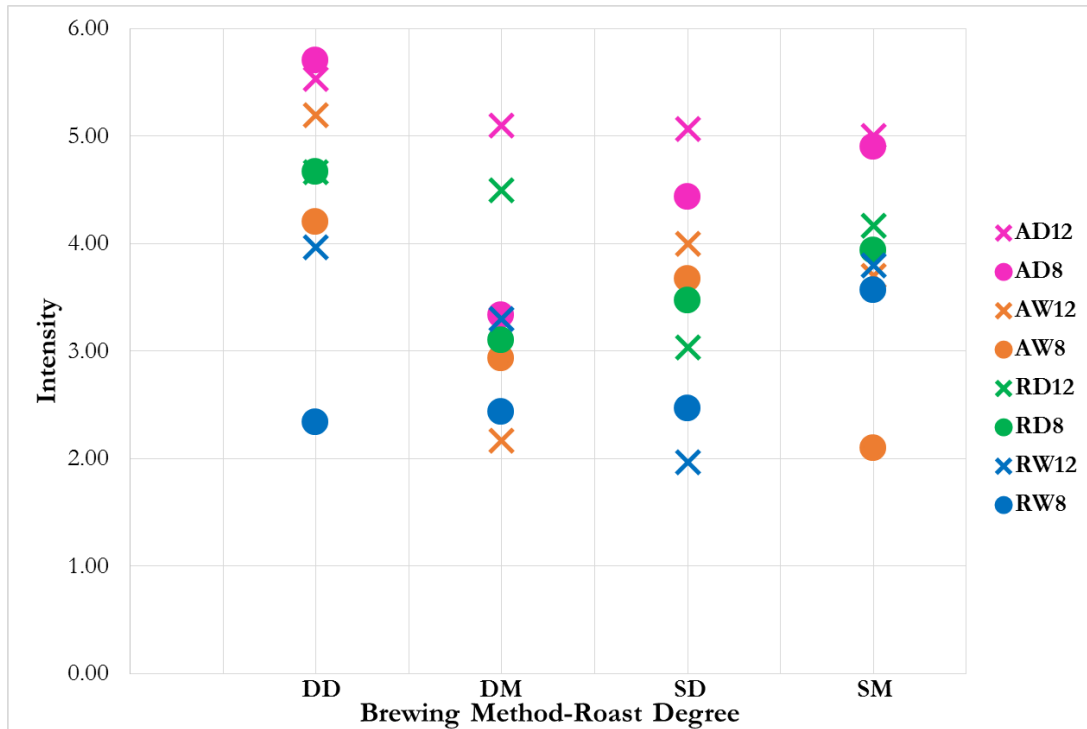


**Figure D-13 Three-way interaction for Musty/Earthy aroma**

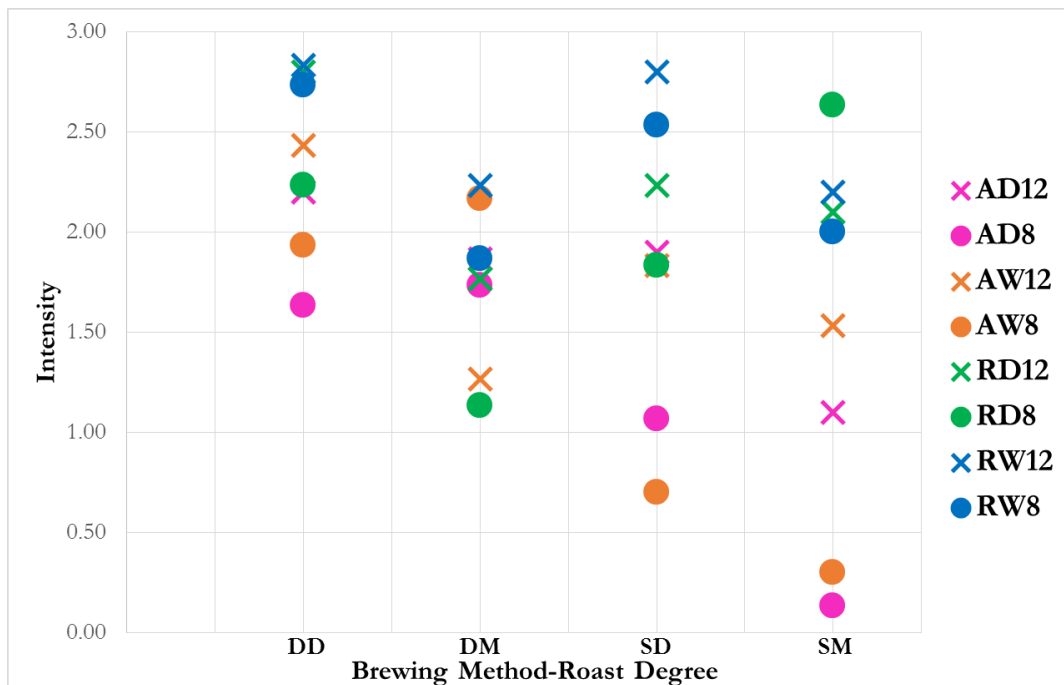


**Figure D-14 Four-way interaction for Stale aroma**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)

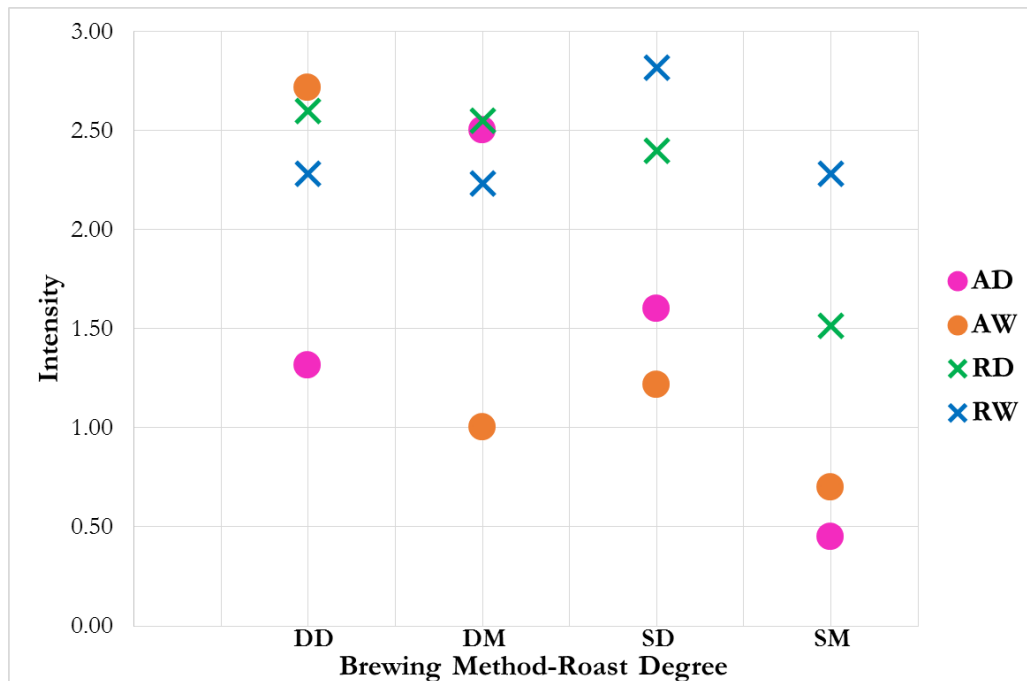


**Figure D-15 Four-way interaction for Fermented aroma**

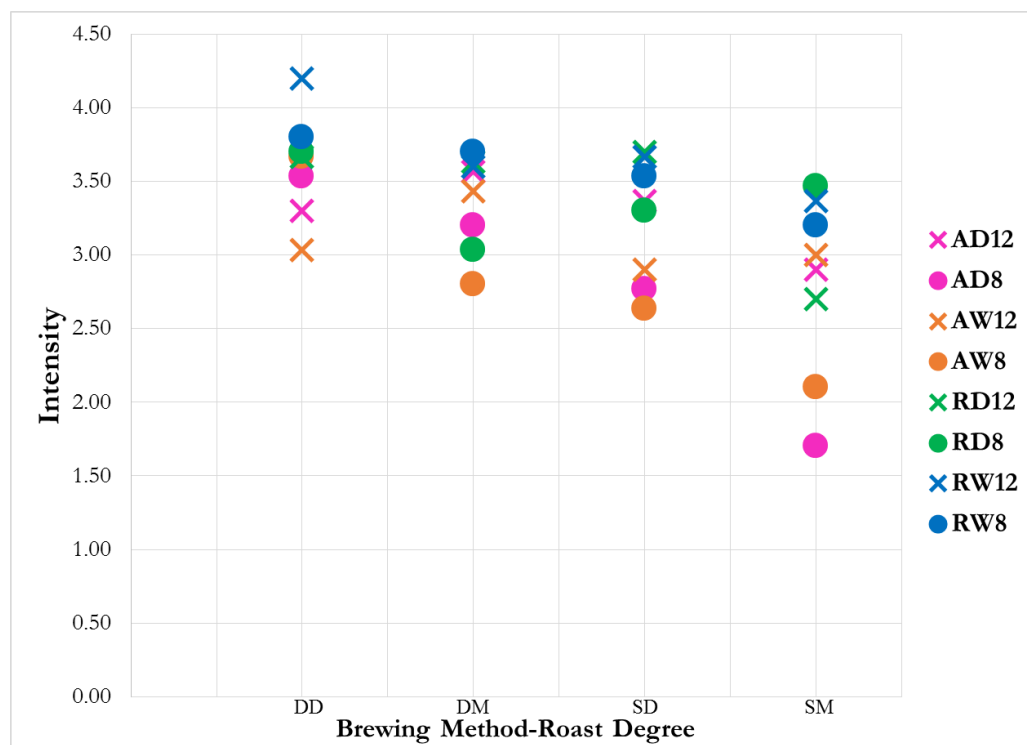


**Figure D-16 Four-way interaction for Smoky flavor**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)

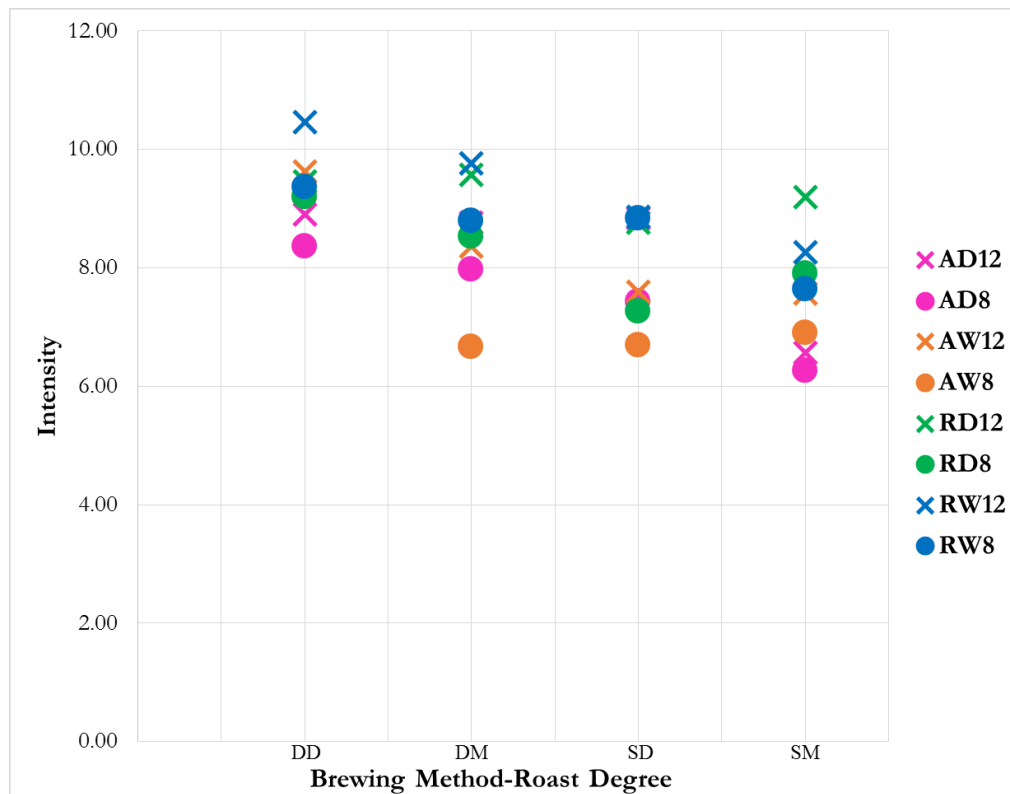


**Figure D-17 Three-way interaction for Ashy flavor**

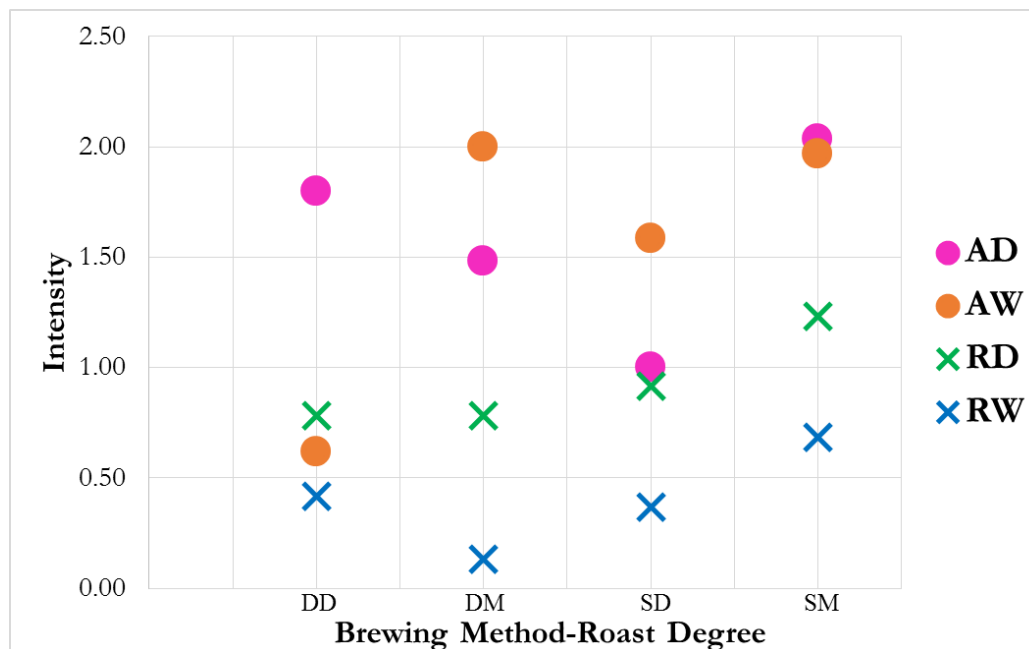


**Figure D-18 Four-way interaction for Woody flavor**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)

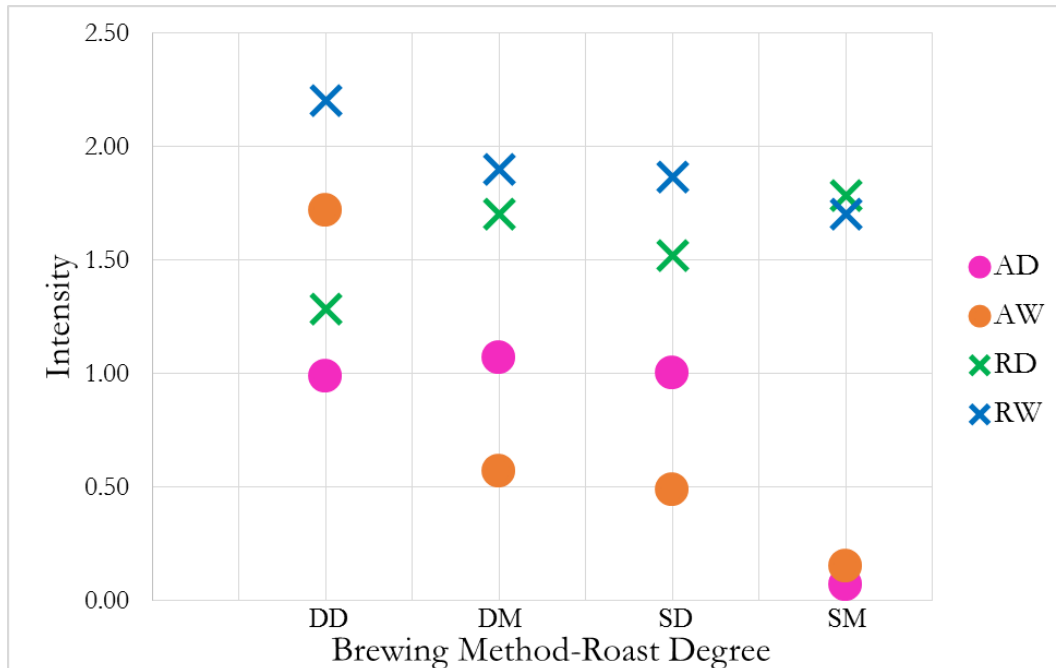


**Figure D-19 Four-way interaction for Roasted flavor**

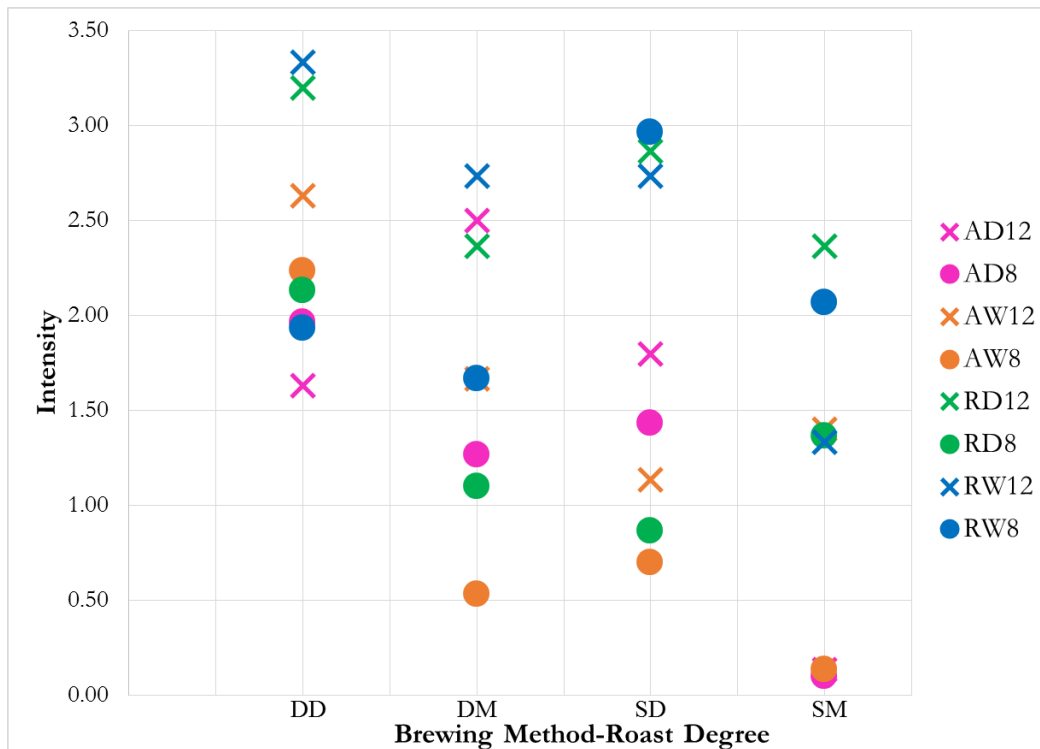


**Figure D-20 Three-way interaction for Sweet Aromatics flavor**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)

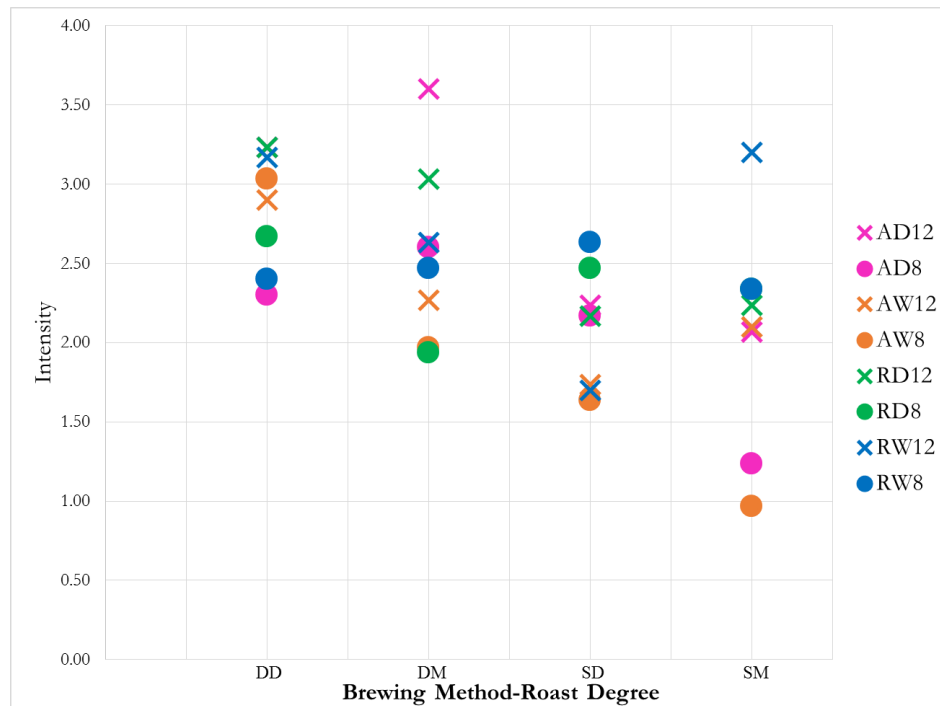


**Figure D-21 Three-way interaction for Burnt flavor**

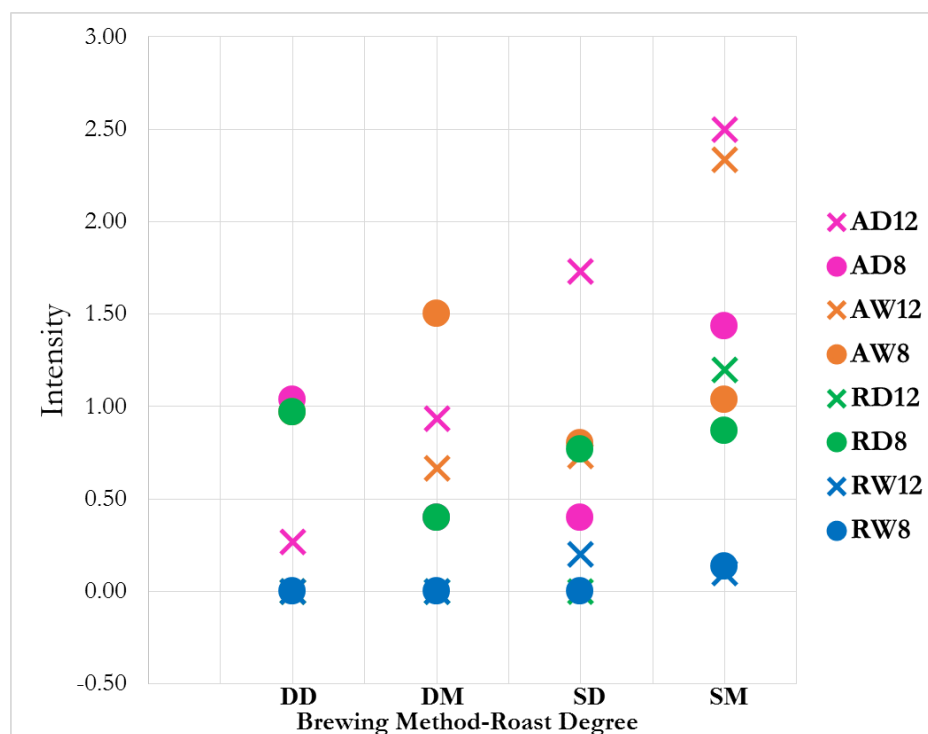


**Figure D-22 Four-way interaction for Acrid flavor**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)

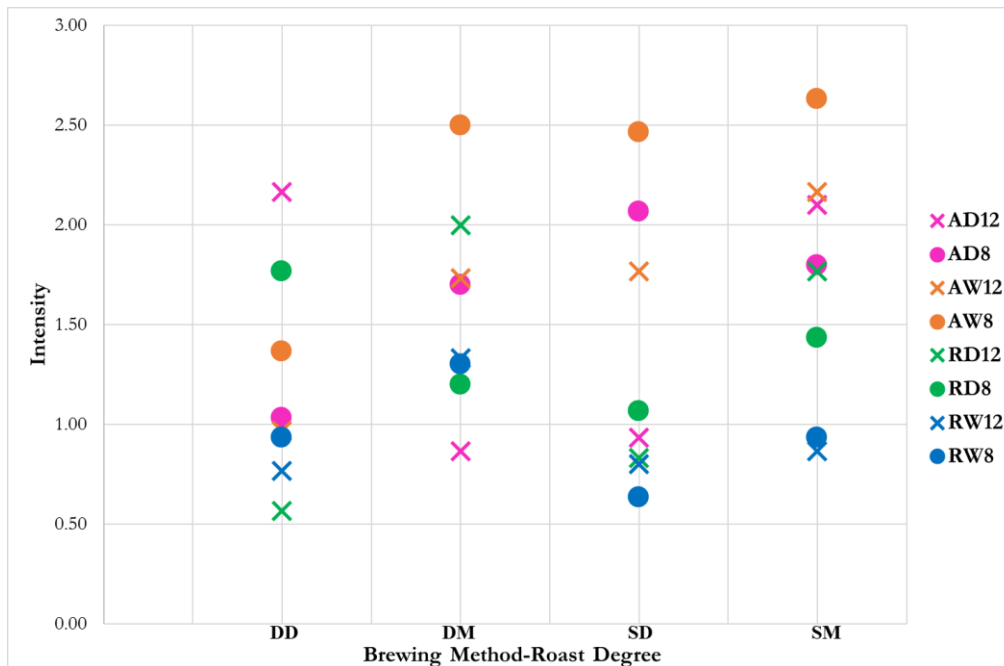


**Figure D-23 Four-way interaction for Chocolate/Dark Chocolate flavor**

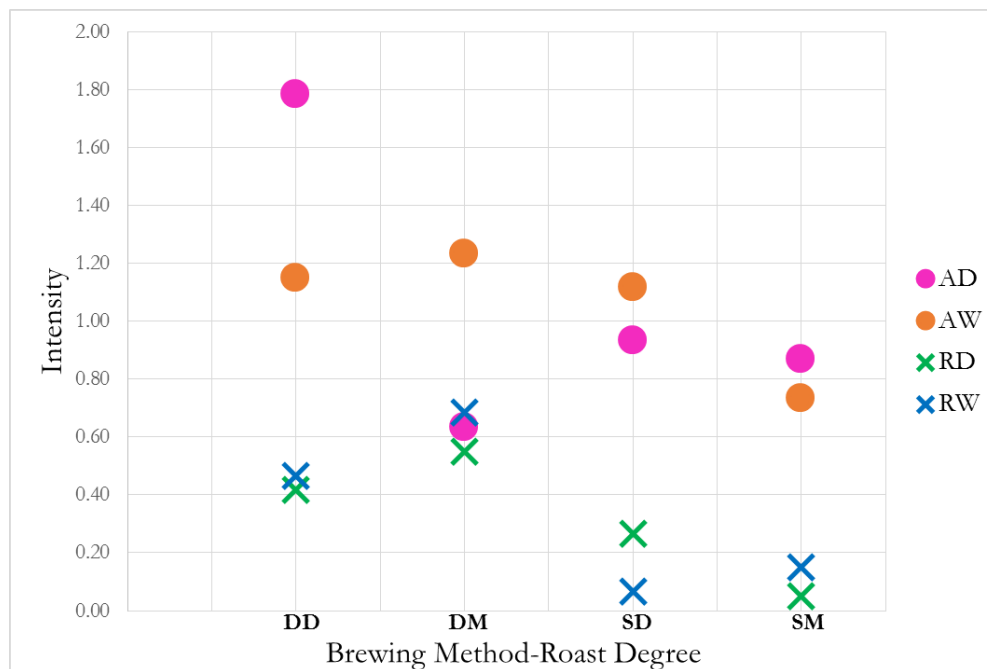


**Figure D-24 Four-way interaction for Green flavor**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)

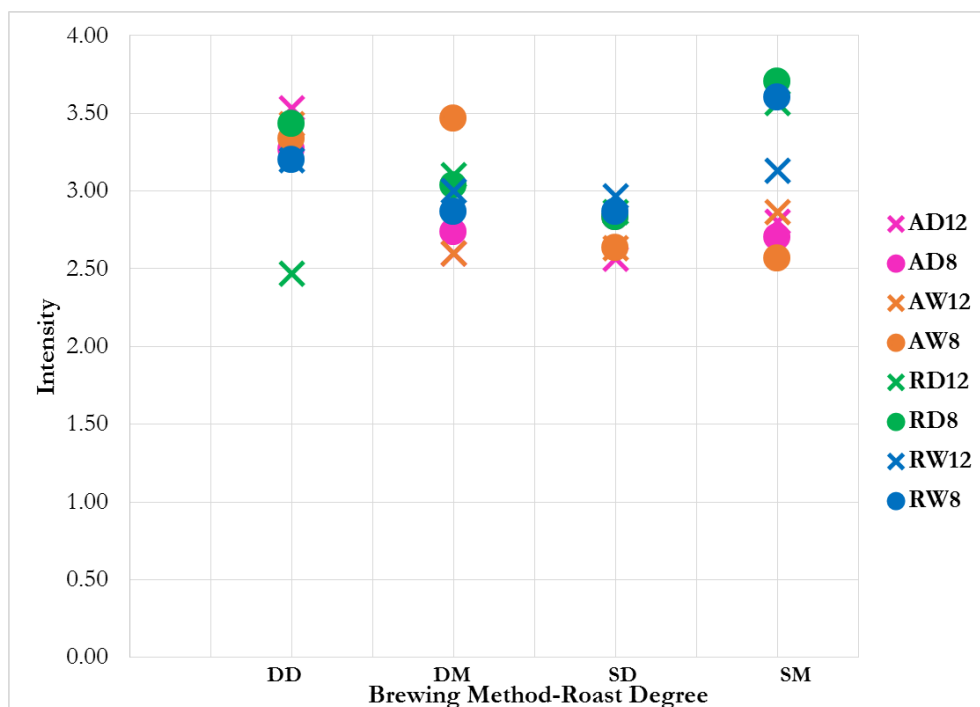


**Figure D-25 Four-way interaction for Nutty flavor**

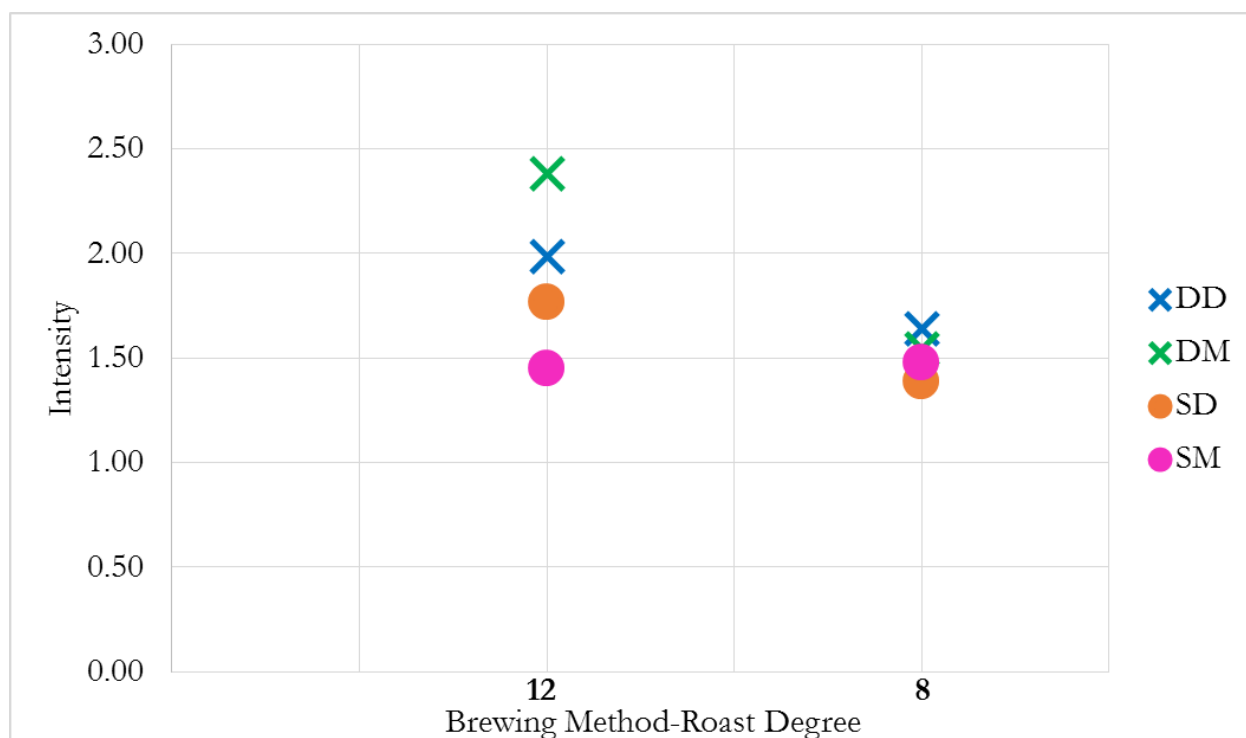


**Figure D-26 Three-way interaction for Floral flavor**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)



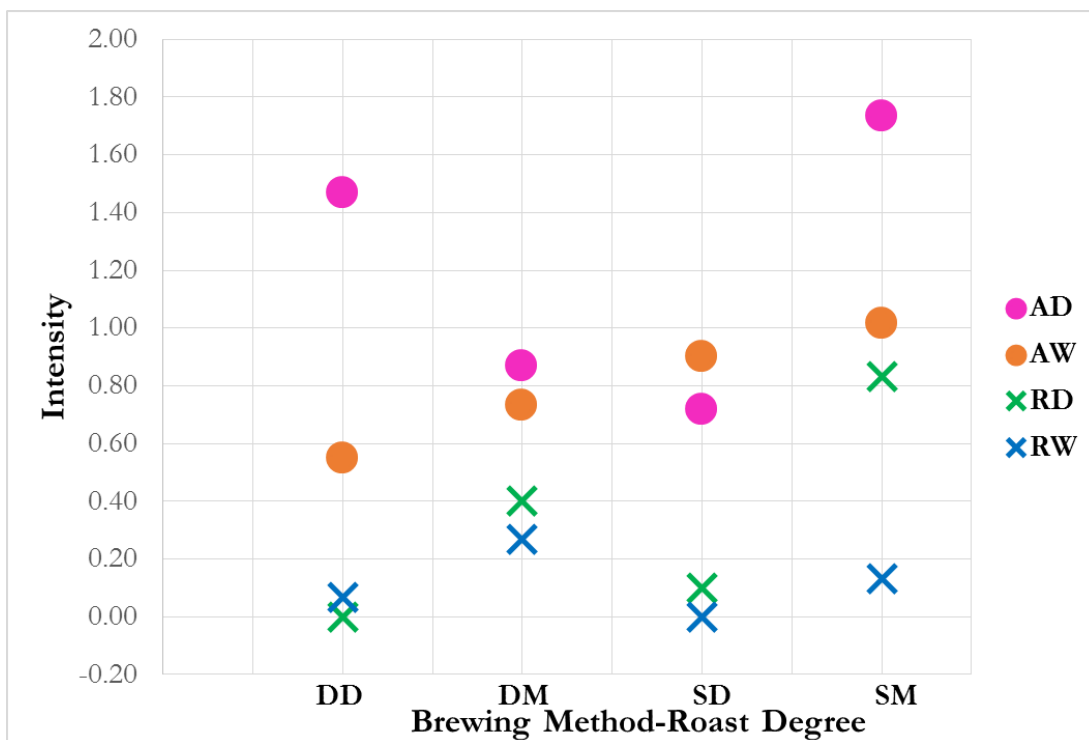
**Figure D-27 Three-way interaction for Cocoa flavor**



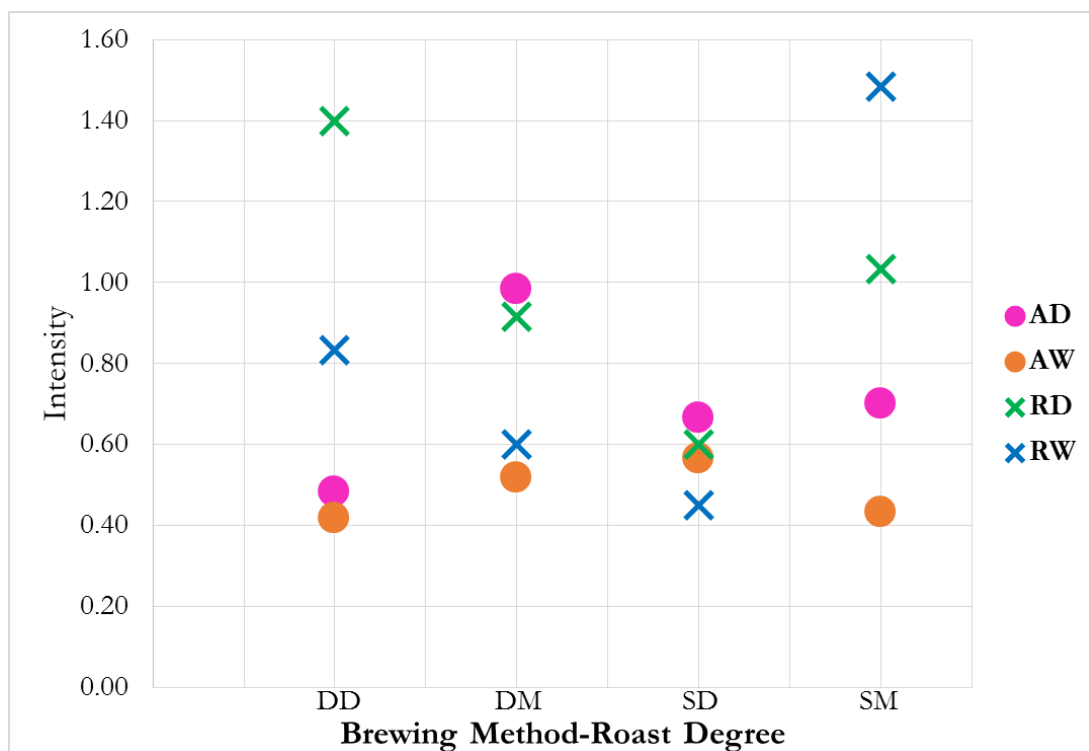
**Figure D-28 Three-way interaction for Musty/Earthy flavor**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)



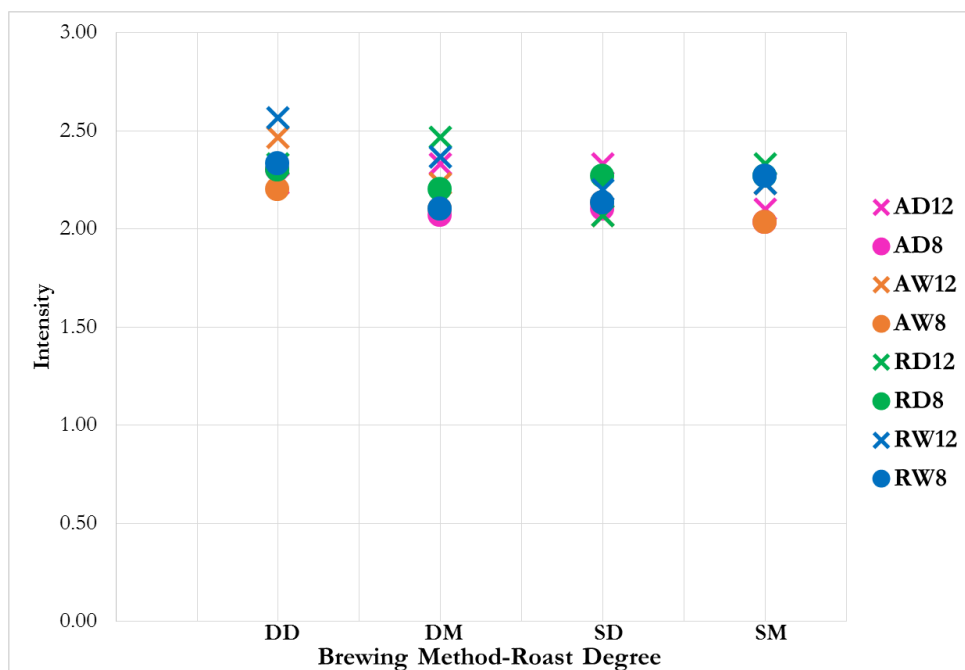


**Figure D-29 Three-way interaction for Sweet taste**

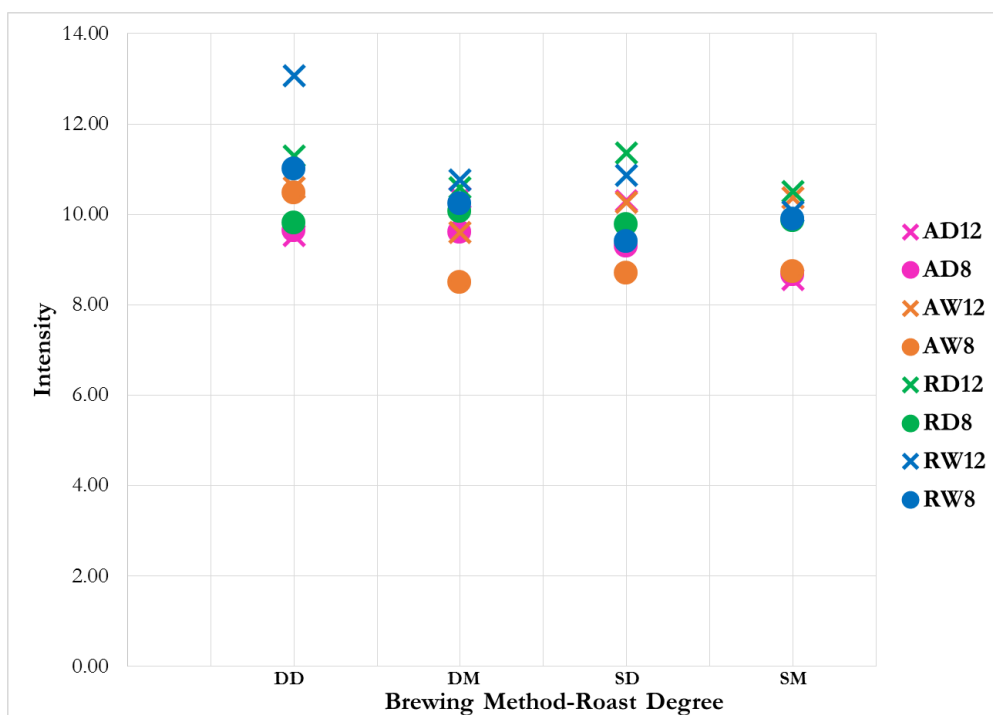


**Figure D-30 Three-way interaction for Stale flavor**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)

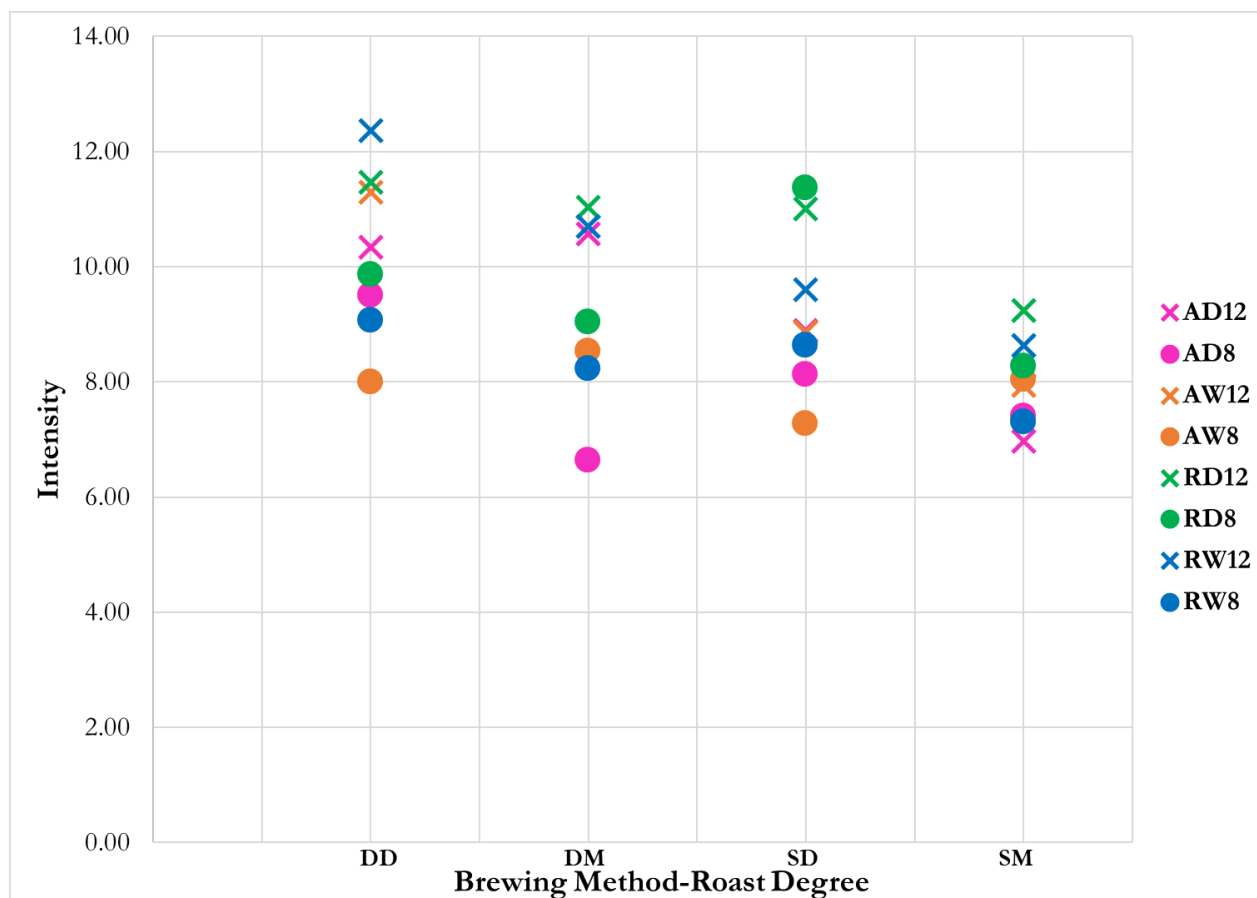


**Figure D-31 Four-way interaction for Mouth drying flavor**



**Figure D-32 Four-way interaction for the Bitter aftertaste**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)



**Figure D-33 Four-way interaction for Longevity**

(DD= Drip method-Dark roast, DM=Drip method-Medium roast, SD=Steep method- Dark roast, SM=Steep method-Medium roast)