Effect of Basket Geometry on the Sensory Quality and Consumer Acceptance of Drip Brewed Coffee

Scott C. Frost, William D. Ristenpart, and Jean-Xavier Guinard

Abstract: In this work, discrimination tests, descriptive analysis, consumer tests, and total dissolved solids (TDS) were used to evaluate the effects of brew basket geometry on the sensory quality and consumer acceptance of drip brewed coffee. Two basic geometries, semi-conical and flat-bottom, were evaluated in conjunction with coffee roast and particle size. Initial discrimination tests showed that small differences in median particle size were not discernable, but that coffees brewed using either semi-conical or flat-bottom filter baskets were significantly different ($P < 0.05$, $N = 45$). Additionally, coffee brewed in the semi-conical basket had significantly higher %TDS, and we estimated a sensory difference threshold of 0.24 %TDS. A subsequent descriptive analysis (DA) showed significant differences by roast for 11 attributes and by grind for six attributes. Although brewing geometry, as a single factor, was only significantly different for three independent attributes (*smoke aroma*, *sweetness*, and *tobacco flavor*), *roast* × *geometry* interactions were significant for six attributes (*berry flavor*, *bitterness*, *burnt wood/ash*, *citrus flavor*, *earthy flavor*, and *sourness*) and the *grind* × *geometry* interaction was significant for two attributes (*bitterness* and *floral aroma*). Attributes showing significant interactions with brewing *geometry* were also key drivers of consumer liking/disliking. Overall consumer liking (9-point hedonic scale) was analyzed by cluster analysis ($N = 85$), which revealed four distinct preference clusters. For each cluster, a particular basket geometry and/or roast level showed lesser acceptance. Overall, the results strongly corroborate the hypothesis that basket geometry affects the sensory quality of drip brewed coffee.

Keywords: basket geometry, consumer liking, descriptive analysis, drip coffee

Practical Application: Most Americans consume drip brewed coffee. Improving our understanding of the effects of basket geometry, roast level, and grind size on the total dissolved solids, sensory properties, and acceptability of drip brewed coffee gives producers and consumers alike an opportunity to optimize the sensory quality of their coffee.

Introduction

The demand for coffee is increasing (USDA, 2018), and previous research has confirmed that consumers desire a variety of flavors and aromas, as well as the promise of sustainability and social responsibility (Arnot, Boxall, & Cash, 2006). With this increased consumer emphasis, understanding how beverage quality is affected during brewing is paramount. Thus, an investigation of how specific brewing methods enhance or detract from the in-cup sensory experience could benefit the consumer experience.

A multitude of biological and physical factors drive coffee flavor. The final cup is a complex chemical mixture resulting from the plant genomics, environmental influences, harvesting and processing techniques, green coffee storage, roasting, grinding, and brewing (Bertrand et al., 2012; Cotter & Hopfer, 2018; Gloess et al., 2013; Läderach et al., 2011; Leroy et al., 2006; Lindinger et al., 2008; Ribeiro et al., 2017; Uman et al., 2016). Green coffee seeds contain the aroma and flavor precursors, which are then transformed during the roasting process (Poisson, Schmalzried, Davidek, Blank, & Kerler, 2009). It is well documented that the roasting of the raw seed is an important driver for many of the impactful coffee flavors, with much of this complexity resulting from the Maillard reaction and Strecker degradation (Bicho, Leitão, Ramalho, de Alvarenga, & Lidon, 2013; Blumberg, Frank, & Hofmann, 2010). Additionally, median particle size has been shown to affect sensory quality as well as the physical process of brewing, and extraction of flavor and aroma compounds into the final beverage (Fuller & Rao, 2017; Uman et al., 2016).

Consumers have a variety of brewing options, both at home and in coffee shops. The preference for a given method can be linked to factors such as lifestyle, culture, social trends, and geography (Pangborn, Guinard, & Davis, 1988), with each brewing method having the capacity to produce coffees of different chemical composition and sensory properties (Caporaso, Genovese, Canela, Civitella, & Sacchi, 2014; Gloess et al., 2013). Drip coffee is a common in-home method first popularized in the 1970's by the Mr. Coffee® brand drip coffeemaker (Abel, 1972). Currently, The National Coffee Association reports 45% of people surveyed in the United States, aged 18 and over, consumed traditional drip coffee the day prior (National Coffee Association, 2018).

Drip coffee follows a common protocol where chemical compounds are extracted and washed out of the coffee as hot water is allowed to "drip" through a bed of coffee grounds and pass through a filter. Consumers have multiple equipment choices for brewing drip coffee, ranging from large capacity automatic machines to those that produce a single cup. A commonality among all drip brewers is the brew basket, which is the physical structure holding the filter and the freshly ground coffee. The brew basket typically has either a "semi-conical" or "flat-bottom" geometry (cf.

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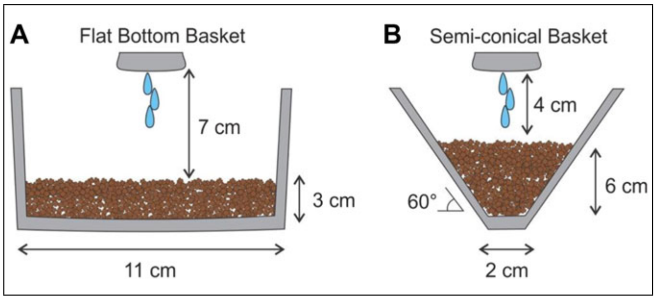

Figure 1–Schematic representation of (A) the flat bottom basket and (B) the semi-conical basket (not to scale). Note the semi-conical basket is not axisymmetric; it is elongated in the direction oriented into the page.

Figure 1). The coffee brewing community is polarized regarding the quality of drip brewed coffee produced from the two different brew basket geometries; there are many anecdotal claims of how one geometry compared with the other yields stronger, more flavorful coffee. Despite the widespread use of the drip brewing method with these two basket geometries, the specifics of how the physical parameters, design, and program of these drip machines affect the flavor of coffee have not been systematically studied. Generally speaking, many researchers have noted that the chemical composition of coffee exhibits complicated dynamics during brewing (Lee, Kempthorne, & Hardy, 1992; Ludwig et al., 2012; Mastdagh, Davidek, Chaumonteuil, Folmer, & Blank, 2014).

In the current study, the effect of basket geometry was examined while also considering the physical coffee parameters of grind and roast level. A series of sensory experiments were performed using coffee prepared in a commercially available drip brewer to determine what differences could be quantified, and how those differences could impact consumer acceptance of drip coffee. For these experiments, brew basket geometry, grind, and roast level were varied, as those are three brewing factors that consumers can easily manipulate. These parameters also affect the overall strength of the coffee brew, which was measured by total dissolved solids (TDS).

Materials and Methods

Coffee origin and preparation

Roast level, brewing basket geometry, and grind distribution were evaluated for each experimental phase as indicated. Two commercially available specialty coffees were used. The roast level of each coffee was determined according to the AGTRON/SCAA gourmet scale (Staub, 1995). The *dark roast* (Agtron 32.0) was a blend of Latin American origin and the *light roast* (Agtron 48.8) was a blend of Colombian and Ethiopian origin. Two basket geometries were compared: a flat-bottom basket, and a semi-conical basket (Figure 1). A Breville Precision brewer was used to brew the coffee, since it was designed to easily allow the semi-conical basket to be inserted directly into the flat-bottom basket and thus alter the brew basket geometry. All coffee was ground using a Mahlkönig Guatemala Lab Grinder set to either grind number 3, 4, or 5. The particle size distribution (Figure 2) for each coffee at each of the three grind settings were measured in triplicate using a Sympatec HELOS/RODOS laser analyzer (Sympatec GmbH, Clausthal-Zellerfel, Germany) equipped with the Sympatec Vibir vibratory feeder and the R7 lens (18 to 3,500 μm). The coffee industry lacks standardized names for specific grind sizes. For the purpose of this work, we refer to the smallest grind with median particle size approximately 800 μm as "fine," the intermediate grind with median particle size of approximately 1,000 μm as "medium," and the coarsest grind with median particle size approximately 1,200 μm as "coarse." We emphasize that these designations might differ from descriptions sometimes used qualitatively in the coffee industry; the grind sizes used here were chosen to bracket the range of grind sizes commonly used for drip brew, and are denoted as "fine" or "coarse" in comparison to each other.

Coffee service

The service of coffee was standardized across all experimental testing. All coffee was brewed and served fresh for each session; at no point was coffee held or partial batch reused. Each coffee was prepared by loading 1,200 g of water into the water tank and 66 g of ground coffee into the brew basket. All brewers were operated on the "gold cup" setting of the Breville Precision brewer (4 mL/s flow rate). The temperature of the water exiting the spray head was 95 °C. The brewer was then given a 2:30 drip out period. For service, a 200 mL ivory-color china (ceramic) mug was used (height 8 cm, opening diameter 7.5 cm, and a bottom diameter of 5.5 cm). Each cup was preheated by pouring boiling water into the cup and allowing it to rest for 60 s. After discarding the heating water, approximately 100 g of coffee was then poured into the cup. The coffee temperature was then measured with a hand-held thermocouple and served at approximately 65 °C. Service temperature was within the range of minimal scald hazard (Brown & Diller, 2008). Coffees were presented in sequential, monadic fashion, that is, a coffee was served, and tasted before the next coffee was served.

Discrimination testing

A two-factor design utilizing geometry (flat-bottom and semi-conical) and grind (fine and medium) as factors was developed. This 2 × 2 design produced four coffees brewed using the light roast. All six combinations (Figure 3) of the four coffees were compared using triangle testing. Data were collected over a 10-day period, during which 14 sessions with a maximum of five participants per session were offered. A total of 45 participants completed all six evaluations. Tasting sessions were conducted in individual, temperature controlled, tasting booths, lit with red lights to mask visual differences among the coffees. For a single session, each triangle was presented in series as described above (section "Coffee service"), along with two unsalted crackers, a cup of water, and an empty cup to expectorate. Prior to evaluating the six triangles, each panelist was presented a demonstration triangle comparing the dark roast and light roast coffees. The presentation order of the six triangles was randomized by session thus, each panelist received the same triangle order, but within a given triangle the odd coffee out was randomized by participant.

Descriptive analysis

Quantitative descriptive analysis (Lawless & Heymann, 2010) was used to describe and quantify the flavor, aroma, and taste differences among the eight coffees brewed to a 2 × 2 × 2 factorial design with roast (dark and light), geometry (flat-bottom and semi-conical), and grind (fine and coarse) as factors. The trained panel was composed of 12 volunteers (six females, six males, between the ages of 18 to 34 years). Panelists were selected based on their interest and availability, but also correct discrimination of four or more coffee pairs as described in section "Coffee service." Each panelist attended five training sessions over a 2-week period. During the initial two sessions, attribute generation was completed with the assistance of the Coffee Taster's Flavor Wheel

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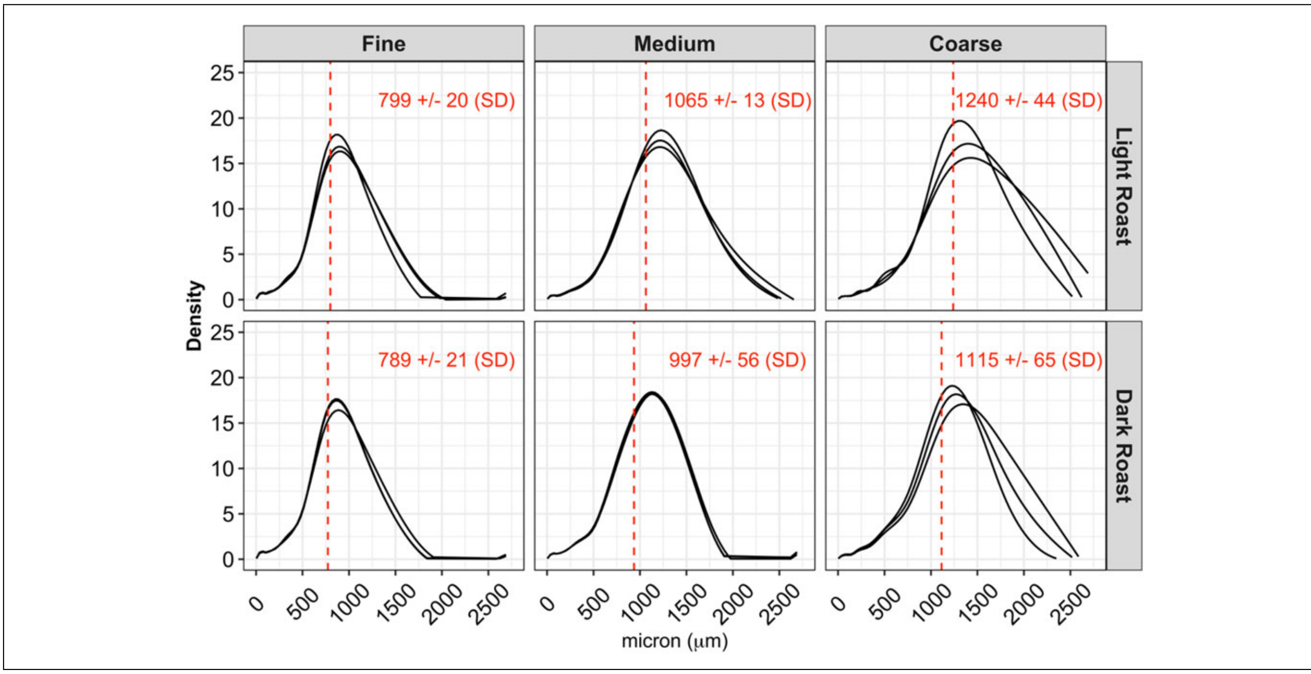

Figure 2–Particle size distribution for each coffee at three different grinder settings. Three replicates per treatment are plotted, with the median particle size numerically indicated at the dashed line.

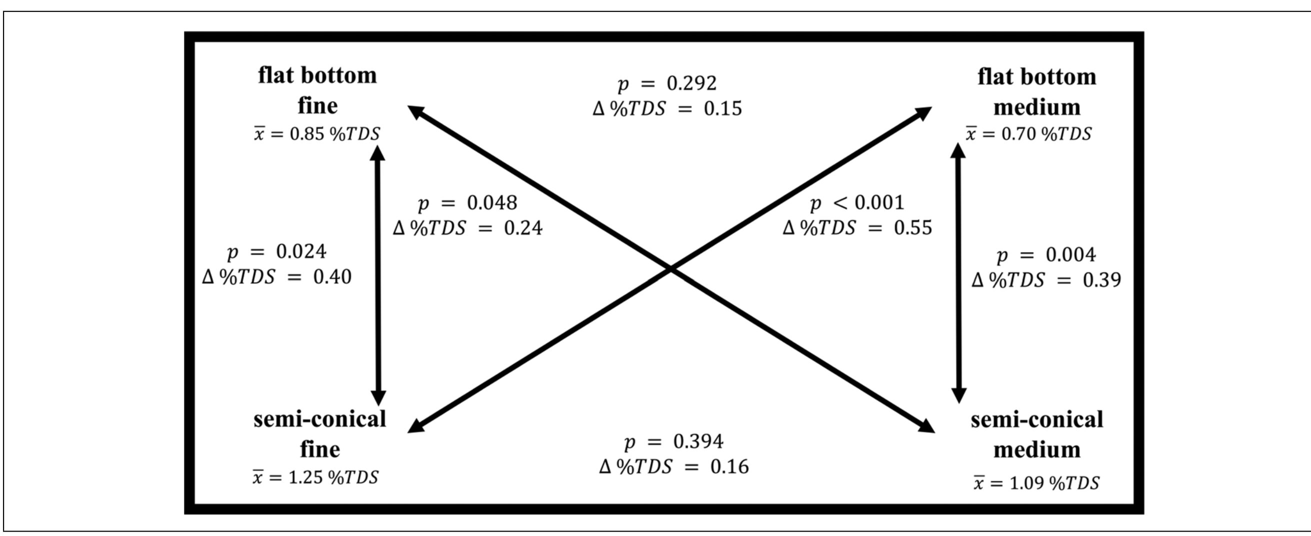

Figure 3–Discrimination testing results showing *P*-values and mean %TDS. Significance between two coffees is indicated with a double head arrow along with the exact *P*-value. The difference in mean %TDS between two coffees is indicated by Δ.

(Chambers et al., 2016; Spencer, Sage, Velez, & Guinard, 2016). Consensus terminology and reference standards (Table 1) were developed over the next three training sessions. Following these, panel alignment was confirmed by in booth testing and analysis of variance (ANOVA) of the data (data not shown). For the formal descriptive analysis, the eight coffees in the design were evaluated in triplicate over four sessions, with six coffees tasted per session following a randomized Williams Latin Square block design to control for possible carry over effects. Evaluations were carried out in temperature-controlled individual tasting booths lit with red lights. Each coffee was served along with two unsalted crackers, a cup of water, and an empty cup to expectorate. Using a provided tablet, panelists first logged into the Red Jade data collection system (Red Jade Sensory Software Solutions, LLC, 2018); they were then served and instructed to begin scoring. Attributes were evaluated in the order shown in Table 1, and scored using a 15 cm unstructured line scale. The line displayed in the tablet had a visual length of 15 cm. Measurements from the 15 cm line scale were then exported as a 100-point scale for data analysis.

Consumer preference

Eighty-five coffee consumers provided preference information through a questionnaire that used the 9-point hedonic scale (Peryam & Pilgrim, 1957), a 5-point just about right scale (JAR), and a check-all-that-apply (CATA) task. Four coffees were

Table 1–Concensus attribute descriptions and preperation method for descriptive analysis standards.

Standard	Preparation
Almond Flavor	Raw almond slices, Diamond brand
Astringency	0.05% Alum solution, McCormick brand
Berry Flavor	1 Tbsp, Private Selection Triple Berry Preserves
Bitterness	0.05% Caffeine
Brown Roast Flavor	1 Tbps, C&H Pure Cane Sugar, Golden Brown
Brown Spice Flavor	1 Tsp each: ground cinamon, ground nutmeg, clove, McCormick brand
Burnt Wood/Ash Flavor	Paper ashes, wood ash, 1 tbsp water
Chocolate Flavor	Nestle Toll House Semi-Sweet Chocolate Morsels
Citrus Flavor	Fresh lemon juice diluted 1:1
Cocoa Flavor	1/4 Cup mixed into 3/4 cup MQ water, Hershey's Cocoa Powder Natural Unsweetened
Dark Green Flavor	Equal parts juice from: Green Giant cut green bean, Del Monte spinach, Del Monte asparagus spears
Dried Fruit Flavor	Sun-Maid prune jucie
Earthy Flavor	Miracle-Gro Potting Mix soil
FloralAroma	Dried chamomile flowers
Grain/Malt Flavor	Equal parts: General Mills Rice Chex, General Mills Wheaties and Quaker Quick Oats cereals
Hay Like Flavor	McCormick Parsley Flakes
Hazelnut Flavor	1 Tbsp, La Tourangelle Artisan Oils Roasted Hazelnut Oil
Molasses Flavor	1/4 Cup mixed into 3/4 cup MQ water, Grandma's Original Molasses (unsulphured)
Musty/Dusty Flavor	Kretschmer Wheat Germ
Raisin Flavor	1/4 Cup Sun-Maid raisins, all choped and microwaved on high for 30 seconds with 1/4 cup MQ water
Rubber Flavor	Rubber bands
SmokeAroma	I Drop, Wright's Liquid Smoke Mesquite
Sourness	0.05% citric acid solution
Sweetness	1.0% sucrose solution
Tobacco Flavor	Camel cigarettes (Turkish and Domestic blend), 1 cigarette crushed
Wood Flavor	Popsicle sticks

evaluated using a two-factor design, with each brewed as a combination of one roast level (dark or light) and one geometry level (flat-bottom or semi-conical). Grind setting 3 was used for all four coffees. Consumers were scheduled and served in groups of five, with each consumer assigned to an individual temperature-controlled tasting booth. Each coffee was prepared and served (as described in section "Coffee service") in random series for each session of five consumers, with a total of 85 consumers over 23 sessions. The ballot questions were as follows.

- Two questions using the 9-point hedonic scale ranging from Dislike Extremely to Like Extremely: 1) "What is your overall opinion of this coffee?" 2) "How much do you like or dislike the overall flavor (taste and aroma) of this coffee?"
- Two JAR questions using a 5-point scale ranging from much too intense to much too weak: 3) "How would you rate the intensity of the coffee flavor?" 4) "How would you rate the intensity of the roast flavor?"
- A final check-all-that-apply (CATA) question: 5) "Which word would you use to best describe the coffee? Check all that apply" from a list of the following descriptors: Sour, Bitter, Cocoa, Citrus, Tobacco, Chocolate, Berry, Rubber, Wood, Raisin, Burnt Wood/Ash, Musty/Dusty, Floral, Smoke, Sweet, Earthy, Dried Fruit, Hay Like.
- After all four coffees were evaluated, consumers filled an exit survey for the following variables: "Age," divided into six possible categories; "Ethnicity," divided into six possible categories; "Gender," four categories; "Cups per day," 0 to 1, 2 to 3, 4 to 5, >5; "What style of coffee do you usually drink?" Drip, Instant, Espresso, Cappuccino, Latte, Moka Pot, French Press; "What do you normally add to coffee?" Brown sugar, white sugar, artificial sweetener, milk, cream, non-dairy, other, nothing; "What style of coffee do you prepare at home?" French Press, Pour Over, Aeropress, Moka Pot, Espresso, Drip, Other, Not at Home.

Percent total dissolved solids (%TDS)

The percentage TDS was measured using a digital refractometer (VST). A 75-mL sample of fresh brewed hot coffee was allowed to cool to room temperature in a covered 100 mL beaker. The refractometer was zeroed with room temperature milli-Q water. The cooled coffee was then mixed and analyzed.

Data analysis

With the exception of the stepwise ANOVA, statistical analysis was performed using R, version 3.5.0 "Joy in Playing" (R Core Team, 2018). Significance of $\alpha = 0.05$ was used for all appropriate methods. The stepwise ANOVA was completed using MATLAB R2017b (The Mathworks, Inc., Natwick, MS, USA).

Discrimination testing. Using the number of correct responses for a given triangle test, the Z-score and P-value were calculated (Lawless & Heymann, 2010).

Descriptive analysis, ANOVA, and principal component analysis. Intensity ratings for each individual descriptive term were analyzed using a five-way fixed effect ANOVA model, with the main effects of *Roast*, *Geometry*, *Grind*, *Judge*, *Replicate* with their two-, three-, and four-way interactions. A stepwise fitting procedure was applied to find the best fit model for each descriptive attribute. The procedure began with the results of the full model, followed by stepwise removal of the highest order nonsignificant term, with the largest P-value. If the factors of the model term selected for removal comprised lower order significant terms, the evaluated term was then retained, and the next highest order nonsignificant term was evaluated. In the absence of a significant interaction, Tukey's least significant difference (LSD) was reported for main effects. Mean separation among interactions was determined by ANOVA using the interaction along with *Judge* and *Replicate* as main effects. Tukey's LSD values were then calculated. Principal component analysis (PCA) was applied to significant attributes determined by ANOVA. Each attribute was scaled to unit variance prior to applying PCA.

Consumer testing. The Euclidean distance between consumers' hedonic ratings for overall opinion was calculated, followed by Ward's hierarchal clustering. Significant effects of treatment and cluster were determined by ANOVA. Significant CATA attributes were determined by applying the Cochran Q test. If significant, Penalty lift was calculated as the difference between overall hedonic means of "checked" and "not checked" descriptors. JAR results were used to calculate the mean drop in hedonic liking (Meyners, Castura, & Carr, 2013).

Results

Discrimination testing

Figure 3 displays the results of the six triangle sets evaluated by 45 participants. Among the four coffees, significant discrimination was shown between the two brewing geometries at an equivalent grind. At the fine grind, 23 of 45 participants ($P = 0.024$) were able to discriminate the coffee brewed between the semi-conical and the flat-bottom baskets. A similar result was found at the medium grind, with 25 correct and $P = 0.004$. Significant differences were not found when the brewing geometry remained constant, but the grind was modified (fine compared with coarse; Figure 3). Using the flat-bottom basket, 18 correct responses were recorded ($P = 0.292$) and 15 correct for the semi-conical ($P = 0.394$). Significant discrimination was also shown between the semi-conical, fine grind compared with the flat-bottom, coarse grind ($P < 0.001$) and the flat-bottom, fine grind compared with the semi-conical, coarse grind ($P = 0.048$).

Descriptive analysis

The five-factor experiment was designed such that each main factor and the interactions among factors could be evaluated. Calculated F-ratios from the iterative fitting method are shown in Table 2. And an additional three-way ANOVA with only the (8) coffees, judges, replications, and their two-way interactions, which we performed for the purpose of panel performance assessment only, is shown in the Supporting Information C. An examination of *F*-ratios in either ANOVA shows that the coffees differed significantly (and by roast, grind, and basked geometry) for a number of sensory attributes. These also speak to the ability of the panel to discriminate among the coffees. Concept alignment and reproducibility of the judges were assessed by examining the *F*-ratios for the judge by coffee (roast/grind/basket geometry) interactions and the *F*-ratios for the replications. They were not significant for the majority of attributes. We conclude that panel performance was adequate for this descriptive analysis.

Table 3 displays the mean attribute intensities for each of the primary experimental factors with significant attributes indicated in bold. Differences by *roast* were shown for 11 descriptive attributes, *grind* was significant for six attributes, and brewing *geometry* for three. Coffees brewed with the dark roasted coffee, irrespective of *geometry* or *grind,* were described by increased *chocolate flavor*, *cocoa flavor*, *hay-like flavor*, *hazelnut flavor*, *musty/ dusty flavor*, *smoke aroma*, *tobacco flavor*, and *wood flavor,* while increased *molasses flavor*, *raisin flavor*, and *sweetness* described the four coffees brewed with the light roast.

G*eometry* showed significant differences for three attributes (*smoke flavor, sweetness*, and *tobacco flavor*, Table 3), but significant interactions were also found for *roast* by *geometry*, and *grind* by *geometry*. Figure 4 displays the *roast* × *geometry* interaction bar plot for each of the six attributes, along with post-hoc means separation (LSD) indicated by letter. *Bitterness, burnt wood/ash flavor*, and *earthy flavor*, each were significantly higher in coffees brewed with dark roast, but when comparing the two geometries within the dark roast brews, *bitterness*, *burnt wood/ash flavor*, and *earthy flavor* were perceived to be higher in the semi-conical than the flat-bottom brewing basket. The light roasted coffee did not show an effect of geometry for perceived *burnt wood/ash flavor*, and *earthy flavor*. However, *bitterness*, within the light roast brews, was significantly more intense when brewed in the semi-conical basket. *Berry flavor, citrus flavor*, and *sourness* were each more intense in the light roast coffee with the semi-conical being perceived as more intense than the flat-bottom geometry. The dark roasted coffee was not affected by basket geometry for perceived *sourness* and *citrus flavor*.

Grind was a significant source of variation for six sensory attributes, *brown roast flavor*, *burnt wood/ash flavor*, *cocoa flavor*, *dark green flavor*, *hay-like flavor*, and *smoke aroma* (Table 3). In each case, attribute intensity increased at the fine *grind* compared with the coarse *grind*. *Grind* showed a significant interaction with *roast* for perceived *dried fruit flavor* and *floral aroma* (Figure 4). Each attribute showed no difference by *roast* at the fine grind, but the coarse grind was perceived as having higher *dried fruit flavor* and *floral aroma* for the lighter roast coffee. Additionally, *bitterness* and *floral aroma* showed a significant *geometry* × *grind* interaction (Figure 4). *Bitterness* decreased at the coarse *grind* for each brewing geometry, but *floral aroma* displays a disordinal interaction. Figure 4 shows the three-way interaction of *rubber flavor,* with each of the eight coffee samples showing various *rubber flavor* intensities.

Principal component analysis shows an overall view of the three treatments (*roast*, *grind*, and *geometry*) in relation to each of the eight brewed coffees. The first two components, plotted in Figure 5, account for 85.5% of variation within the descriptive analysis dataset. Along the first principal component, the coffees are discriminated by *roast*, with the four dark roast coffees to the right and the four light *roast* coffees to the left. Within the light *roast* coffees, *grind* separates along the first principal component with the fine grind closer to the plot origin. Additionally, light roast separates by brewing *geometry* along the second principal component. The four dark *roast* coffees do not show a similar discrimination as the light *roast* coffees. Dr-Co-Fine, Dr-Fb-Fine, and Dr-Co-Coarse are positioned together with Dr-Fb-Coarse found in the negative direction of the second component.

The relationship between PCA scores and loadings shows similar results as the ANOVA. *Berry flavor*, *citrus flavor*, and *sourness* were shown to have an interaction between roast and geometry, which is echoed by the position of Lr-Co-Fine and Lr-Co-Coarse coffees. The separation of the light *roast* by grind along the first PC can be attributed to the *dried fruit flavor* and *floral aroma*. Each of these attributes showed significant interaction between *roast* and *grind*. The *roast* × *geometry* interaction for *bitterness*, *burnt wood/ash flavor*, and *earthy flavor* is also shown in the PCA.

Consumer acceptance

Hedonic ratings and cluster analysis. The collected demographics of the 85 consumers are shown in Table 4. The majority of consumers were women (62.4%), aged 18 to 24 years (80.0%), of Asian or Pacific Islander descent (43.5%), consuming zero to one cup of coffee per day (57.6%). Within the 85 consumers, a significant overall liking was not shown for a specific evaluated factor (coffee, roast level, or brewing geometry). This extended to both liking questions regarding overall opinion of the coffee and liking of the coffee flavor, but a strong correlation between opinion of the coffee and liking of the coffee flavor was found ($r = 0.90$, $df = 338$).

Table 2–Table of F-ratios, significance ($P < 0.05$) indicated with“*”.

	d.f.	Almond Flavor	Astringent Mouthfeel	Berry Flavor	Bitter Taste	Brown Roast Flavor	Brown Spice Flavor	Burnt Wood/ Ash Flavor	Chocolate Flavor	Citrus Flavor	Cocoa Flavor	Dark Green Flavor	Dried Fruit Flavor	Earthy Flavor
1														
Geometry	1		0.08	**5.49***	**56.46***	0.30		**7.43***	0.05	**12.76***		1.44	3.76	3.36
Grind	1	2.37	2.65		**33.73***	**17.34***		**6.93***	2.52	0.08	**6.07***	**5.29***	0.26	3.27
Judge	11	**9.86***	**11.37***	**35.94***	**8.99***	**34.97***	**26.38***	**10.35***	**15.11***	**21.63***	**27.70***	**28.55***	**13.94***	**16.26***
Rep	2	0.74	0.47	0.90	**7.27***	2.80	1.22	**6.59***	1.37	0.06	2.35	**3.58***	0.66	0.62
Roast	1	0.10	2.98	**93.64***	**263***		0.05	**122.76***	**21.15***	**94.27***	**10.57***	1.41	**26.31***	**69.23***
2														
Geometry*Grind	1		1.53	0.32	**4.17***				1.04			0.04	0.74	
Geometry*Judge	11		1.94	**2.63***	0.96	**2.29***			0.85			1.93	**2.19***	
Geometry*Rep	2		1.41	0.41	0.39				1.16			0.74	1.30	
Grind*Judge	11	0.69	**3.62***	**2.55***	0.30	**2.76***			0.77			**2.26***	0.61	
Grind*Rep	2	0.86	1.10	1.03		1.36	1.44		0.51	**3.71***		0.09		**3.32***
Judge*Rep	22	1.18	**2.76***	**2.5***	1.29	**2.05***	**2.38***		1.00	**1.61***	**2.47***	**1.94***		
Roast*Geometry	1		0.57	**6.45***	**9.68***			**5.00***		**15.25***		0.46	1.70	**5.89***
Roast*Grind	1		0.24	3.64		0.36	1.15					0.09	**5.18***	1.19
Roast*Judge	11	**4.00***	**2.16***	**4.11***	**6.72***	**13.6***	1.30	**3.44***	**4.02***	**3.33***	**2.50***	**3.04***	**2.29***	
Roast*Rep	2		0.44	1.17		1.23	1.63	**4.41***				**3.79***	1.43	1.46
3														
Geometry*Grind*Judge	11		0.59	**2.33***	**1.99***				0.33			1.75	**2.12***	
Geometry*Grind*Rep	2		**4.59***						0.41			0.54		
Geometry*Judge*Rep	22		1.27	0.89	**1.66***				1.61			1.35		
Grind*Judge*Rep	22	**1.74***	1.43	1.19		**4.37***			1.05			1.50		
Roast*Geometry*Grind	1		0.02	2.82								2.10		
Roast*Geometry*Judge	11		1.14	1.41								1.50		
Roast*Geometry*Rep	2			0.16								0.02	**3.27***	
Roast*Grind*Judge	11		0.74	1.37		1.5						**2.77***		
Roast*Grind*Rep	2		0.51	**4.15***		1.28	**3.74***					0.67		**3.08***
Roast*Judge*Rep	22		0.96	**2.64***		**1.63***	**1.78***					**2.76***		
4														
Geometry*Grind*Judge*Rep	22		**2.12***						**2.56***			**1.72***		
Roast*Geometry*Grind*Judge	11		**2.36***	**3.58***								**2.62***		
Roast*Geometry*Grind*Rep	2											**3.18***		
Roast*Geometry*Judge*Rep	22			**3.32***										
Roast*Grind*Judge*Rep	22		**1.87***	**2.44***		**1.99***								

(Continued)

Sensory & Consumer Sciences

Table 2–Continued.

	d.f.	*Floral Aroma*	*Gain/Malt Flavor*	*Hay-Like Flavor*	*Hazelnut Flavor*	*Molasses Flavor*	*Musty/ Dusty Flavor*	*Raisin Flavor*	*Rubber Flavor*	*Smoke Aroma*	*Sour Taste*	*Sweet Taste*	*Tobacco Flavor*	*Wood Flavor*
1														
Geometry	**1**	0.01		0.73		3.47		2.73	**5.90***	**3.94***	**29.26***	**5.46***	**19.00***	
Grind	**1**	2.79		**4.78***				0.43	0.43	**7.13***	0.03		1.96	
Judge	**11**	**19.40***	**10.22***	**21.14***	**19.09***	**25.86***	**3.74***	**16.10***	**16.74***	**9.42***	**13.22***	**18.23***	**18.29***	**17.15***
Rep	**2**	2.14		1.42		**5.01***		0.22	0.03	**4.79***	**4.77***		**6.93***	
Roast	**1**	**19.32***	1.37	**16.59***	**4.11***	**8.51***	**37.19***	**18.50***	**52.07***	**69.28***	**103.12***	**36.32***	**45.59***	**36.76***
2														
Geometry*Grind	**1**	**11.66***				0.53		1.96	2.94	1.80			0.28	
Geometry*Judge	**11**	1.52		**2.01***		1.69		0.96	**3.38***	1.23	**2.33***		1.13	
Geometry*Rep	**2**	0.06				0.69							2.30	
Grind*Judge	**11**	0.77		1.86		1.20		1.07	**2.79***	1.37			0.90	
Grind*Rep	**2**	2.54		0.86		1.59				1.81	0.27			
Judge*Rep	**22**	**1.92***		0.46		1.55		**1.75***	**1.73***	**2.09***			**1.84***	
Roast*Geometry	**1**					0.40			0.36	2.64	**9.74***		3.46	
Roast*Grind	**1**	**4.12***		1.00		0.01			0.03		2.46			
Roast*Judge	**11**	**3.03***	**2.62***	**2.16***	**2.60***	**3.27***	**1.83***	**2.91***	**6.21***	**4.89***	**2.14***	**8.05***	**3.77***	
Roast*Rep	**2**			1.85		0.30					0.26		**5.08***	
3														
Geometry*Grind*Judge	**11**	0.68				**2.59***		**2.29***		**1.94***			**2.05***	
Geometry*Grind*Rep	**2**	0.28				**3.15***								
Geometry*Judge*Rep	**22**	0.69				**1.89***							**1.97***	
Grind*Judge*Rep	**22**	1.59		1.37		0.96				**2.29***				
Roast*Geometry*Grind	**1**					0.87			**7.17***					
Roast*Geometry*Judge	**11**					1.86			**2.26***	**1.93***			**2.93***	
Roast*Geometry*Rep	**2**					**3.24***								
Roast*Grind*Judge	**11**			1.30		1.82								
Roast*Grind*Rep	**2**			**4.66***							4.87*			
Roast*Judge*Rep	**22**			1.00										
4														
Geometry*Grind*Judge*Rep	**22**	**1.64***				**1.67***								
Roast*Geometry*Grind*Judge	**11**					**2.46***								
Roast*Geometry*Grind*Rep	**2**													
Roast*Geometry*Judge*Rep	**22**													
Roast*Grind*Judge*Rep	**22**			**2.26***										

Sensory & Consumer Sciences

Table 3–Mean attribute intensities for each factor. Significance indicated by "*". If an interaction was determined to be significant, main effect significance was not reported.

	Roast			Geometry			Grind		
	Dark	*Light*	*LSD*	*Flat Bottom*	*Semi-Conical*	*LSD*	*Fine*	*Coarse*	*LSD*
Almond Flavor	16.76	16.36		16.59	16.53		17.53	15.58	
Astringency	40.21	37.27		38.49	38.99		40.13	37.35	
Berry Flavor	16.61	28.94		21.28	24.27		22.81	22.74	
Bitterness	53.87	27.73		34.74	46.85		45.48	36.12	
Brown Roast Flavor	31.11	31.07		30.73	31.45		**33.82***	28.36	2.59
Brown Spice Flavor	16.93	16.65		16.27	17.31		16.83	16.75	
Burnt Wood/Ash Flavor	40.62	19.25		27.31	32.56		**32.47***	27.40	3.80
Chocolate Flavor	**28.49***	20.60	3.39	24.36	24.74		25.91	23.19	
Citrus Flavor	15.02	29.22		19.51	24.73		22.32	21.92	
Cocoa Flavor	**24.20***	19.26	2.99	21.49	21.97		**23.60***	19.86	2.99
Dark Green Flavor	25.19	23.60		23.60	25.20		**25.94***	22.86	2.67
Dried Fruit Flavor	16.95	23.69		21.60	19.05		19.99	20.66	
Earthy Flavor	35.19	21.76		26.99	29.95		29.93	27.01	
Floral Aroma	31.23	39.20		35.32	35.11		33.70	36.73	
Gain/Malt Flavor	24.96	23.18		25.35	22.79		23.90	24.24	
Hay Like Flavor	**23.61***	18.42	2.52	20.47	21.56		**22.41***	19.63	2.52
Hazelnut Flavor	**20.34***	17.48	2.78	19.89	17.93		19.62	18.20	
Molasses Flavor	19.42	**22.96***	2.41	20.06	22.32		21.17	21.21	
Musty/Dusty Flavor	**29.76***	19.32	3.37	24.16	24.92		25.06	24.01	
Raisin Flavor	14.82	**20.28***	2.50	16.50	18.60		17.97	17.13	
Rubber Flavor	26.29	15.38		19.00	22.67		21.33	20.34	
Smoke Aroma	**46.01***	31.99	3.33	37.33	**40.67***	3.33	**41.25***	36.75	3.33
Sourness	22.40	40.03		26.52	35.91		31.06	31.37	
Sweetness	19.50	**27.83***	2.72	**25.28***	22.05	2.72	24.06	23.27	
Tobacco Flavor	**24.99***	15.24	2.85	16.97	**23.26***	2.85	21.13	19.10	
Wood Flavor	**27.64***	18.70	2.90	22.74	23.60		24.40	21.94	

In order to investigate if preference among sub-segments of consumers could be identified, cluster analysis was applied to the matrix of hedonic ratings (overall opinion of the coffee). The resulting dendrogram is shown in the upper portion of Figure 6, shaded by the four clusters. The violin plots below the dendrogram display hedonic ratings by each cluster for each coffee. The upper set of panels corresponds to the distribution of opinions of the coffees' flavor, and lower set shows overall opinion of the coffees. Each cluster shows a general acceptance for three out of the four coffees, and dislike for the fourth coffee. Cluster 1 disliked the dark roast semi-conical, cluster 2 disliked the light roast semi-conical, cluster 3 disliked the dark roast flat-bottom, and cluster 4 disliked the light roast flat-bottom.

Check-all-that-apply (CATA). Consumers indicated their sensory perceptions of each coffee through CATA. An attribute list was generated using 18 significant descriptors from the descriptive analysis (Table 3). Significance among CATA terms was determined by applying the Cochran Q test to each attribute. The selection of all terms with the exception of *earthy flavor*, *cocoa flavor*, and *chocolate flavor* varied significantly across the evaluated coffees. Overall panelist usage of the 18 listed attributes is shown in Figure 7 as a stacked bar plot. The total height of each bar indicates the total usage percentage of a given descriptor, for example, bitterness was used 5% of the time. This was determined, as 85 consumers each evaluated four coffees, for a total of 340 possible instances where bitterness could be checked, of which bitterness was selected 175 times (51.5%). Each bar is further labeled with the usage percentage for a given coffee, calculated as the percentage of the 85 consumers for a specific coffee (for example, 62.4% of consumers checked *bitterness* for the dark roast flat bottom coffee). *Bitterness* was the most used term for all coffees, followed by *smoke aroma*, *burnt wood/ash flavor*, *earthy flavor*, and *sourness* with each used approximately 35% of the time. Term usage differed by *roast* as dark roast was described by *bitterness*, *burnt wood/ash flavor*, *smoke aroma*, and *wood aroma*. This result was in contrast to the light roast coffee described by *sourness*, *bitterness*, *berry flavor*, and *citrus flavor.*

CATA-lift analysis was applied to evaluate changes in hedonic ratings (9-point scale) when a specific CATA attribute was perceived compared with not perceived. Figure 8 displays the mean hedonic difference for each of the 15 significant CATA attributes for each of the two hedonic questions. For example, when *floral* was checked, a 1-point mean increase in overall opinion was found. Liking increased when *floral*, *sweetness*, *berry*, or *dried fruit* were indicated, while liking decreased when consumers perceived *rubber*, *burnt wood/ash*, *musty/dusty*, or *bitter*.

JAR: Mean drop by cluster and cluster descriptions. Mean drop analysis was applied to evaluate how consumers perceived the intensity of the coffee flavor and the intensity of the roast flavor within the context of the two liking questions. Table 5 displays the mean liking drop for each JAR attribute rating. Additionally, the analysis was applied by cluster, to determine cluster preference behavior. Cluster 1 showed a significant *moderate dislike* for the dark roast semi-conical brew (Figure 6). When asked to rate the roast flavor (JAR), 81.3% of cluster 1 responded that the dark roast semi-conical brew was too strong in roast flavor with a mean drop of −2.62 points in *overall liking of the coffee flavor* and −3.44 points in *overall opinion of the coffee*. Cluster 1 also showed a similar response to the dark roast flat-bottom brew, reporting drops of −2.01 and −1.50 when asked to rate the roast flavor. When asked to rate the intensity of coffee flavor, a similar response was seen as with roast flavor for the dark roast semi-conical, but not the dark roast flat-bottom. The coffee flavor of the dark roast semi-conical brew was perceived as too strong by 68.8% of cluster 1, with a penalty of −2.89 points against *overall liking of the coffee flavor* and −3.23 points drop against *overall opinion of the coffee*. Overall, cluster 1 did not prefer the dark roast coffee, especially when brewed in the semi-conical basket,

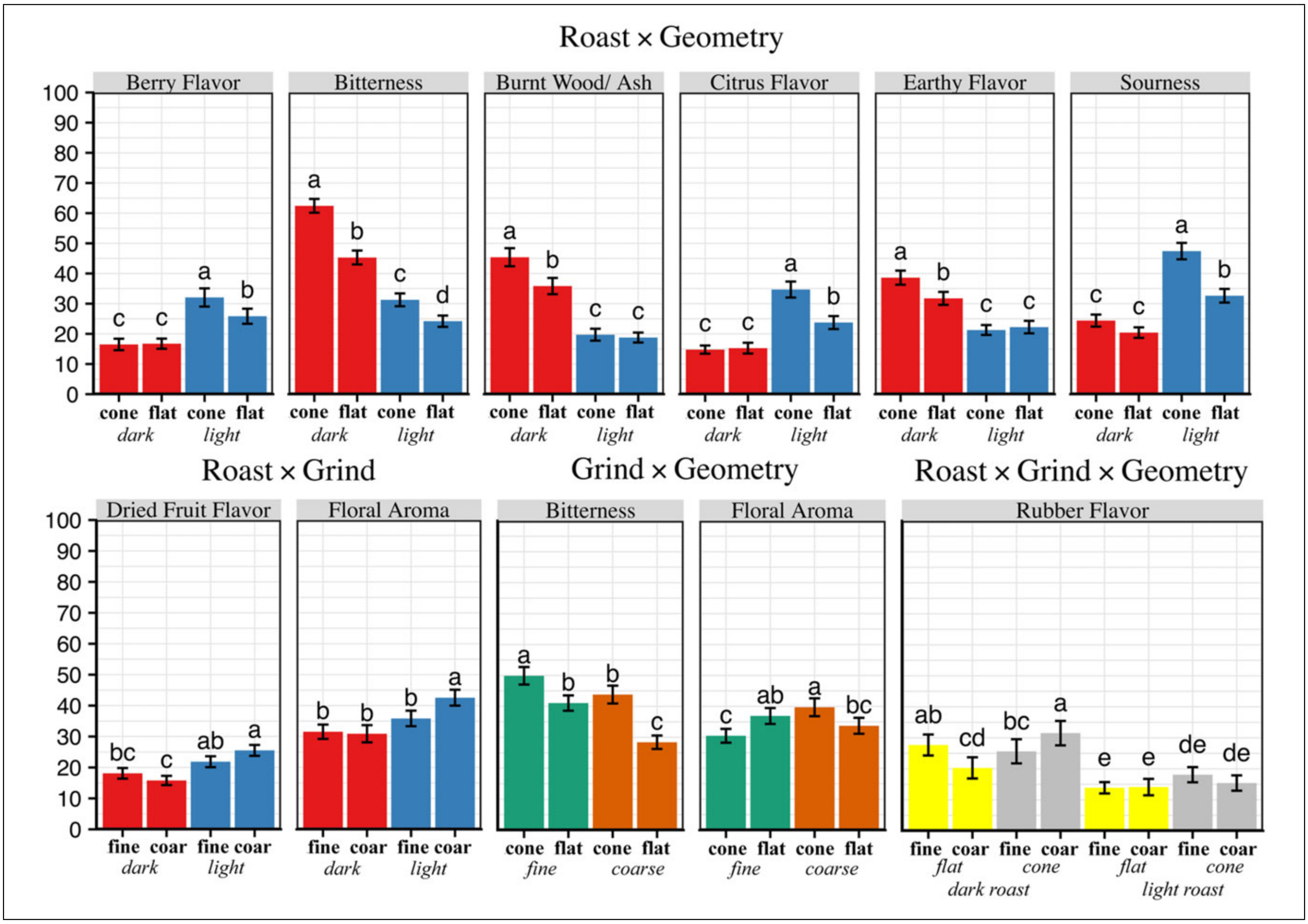

Figure 4–Mean intensities by significant interaction for descriptive attributes. Values within a given attribute that share the same letter are not significantly different.

but found the two light roast coffees to be "JAR." Cluster 1 was composed of consumers who enjoyed drip coffee, French press, and latte style coffees (Table 4), but tend to not prepare coffee at home.

Cluster 2 showed a significant *slight dislike* for the light roast semi-conical brew (Figure 6). Mean drop analysis showed that 48.0% of the cluster indicated that the brew was too strong in roast flavor with a penalty of −2.75 points against *overall liking of the coffee flavor* and −2.88 points against *overall opinion of the coffee*. Additionally, cluster 2 found the dark roast semi-conical to have too strong a roast flavor and too strong of a coffee flavor, but the mean drop is not as sharp (Table 5). Consumers of cluster 2 are likely responding to the %TDS of the coffee, showing a significant dislike for the light roast semi-conical, but also responding to the roast flavor of the dark roast semi-conical.

The dark roast was found to have too strong a roast flavor for both the flat-bottom and semi-conical brews by consumers in cluster 3. This cluster reports acceptance drops that range from −1.89 to −3.62. Cluster 3 shows a similar dislike for the dark roast brews as cluster 1, with the light roast brews reported as "JAR." Cluster 3 reports the highest percentage of consumers who consume drip (72.0%) and espresso (52.0%), but the lowest percentage who consume cappuccino (16.0%) and latte (40.0%). Clusters 1 and 3 can be contrasted with cluster 4, as cluster 4 reported the light roast flat-bottom to have weak roast flavor and weak coffee flavor.

Percent total dissolved solids

Measured total dissolved solids (%TDS) from the three phases of sensory testing are displayed in Figure 9. Overlaid boxplots show the distribution for each specific coffee with the mean indicated by a bold square. A one-way ANOVA showed significantly different mean %TDS among the 10 different coffees brewed across all phases of sensory evaluation (Supporting Information A). A recurring observation is that the %TDS varied from brew to brew even under the same conditions, with ranges as large as 0.65% to 1.0% (for the flat bottom/fine grind) to as small as 1.2% to 1.3% (for conical/fine grind). In general, the conical basket yielded higher brew strengths.

A three-factor analysis of variance with *Roast*, *Geometry,* and *Grind* was applied to the %TDS measures collected during the descriptive analysis (see Supporting Information A). Main effects of *grind* and *geometry* were significant, along with the three-way interaction (*roast* × *geometry* × *grind*). Within *geometry*, the semi-conical brewing basket produced coffees with significantly higher %TDS concentrations over the flat-bottom basket. This result is visualized in Figure 8, as the four coffees brewed in the semi-conical geometry each show a higher mean %TDS concentration. The fine *grind* produced the highest mean %TDS within each specific geometry. A wide distribution of values was reported for the flat-bottom brew basket at the fine grind. In order to best compare the three-way *Roast* × *Geometry* × *Grind* interaction, a one-way ANOVA utilizing each of the eight coffees was applied, followed

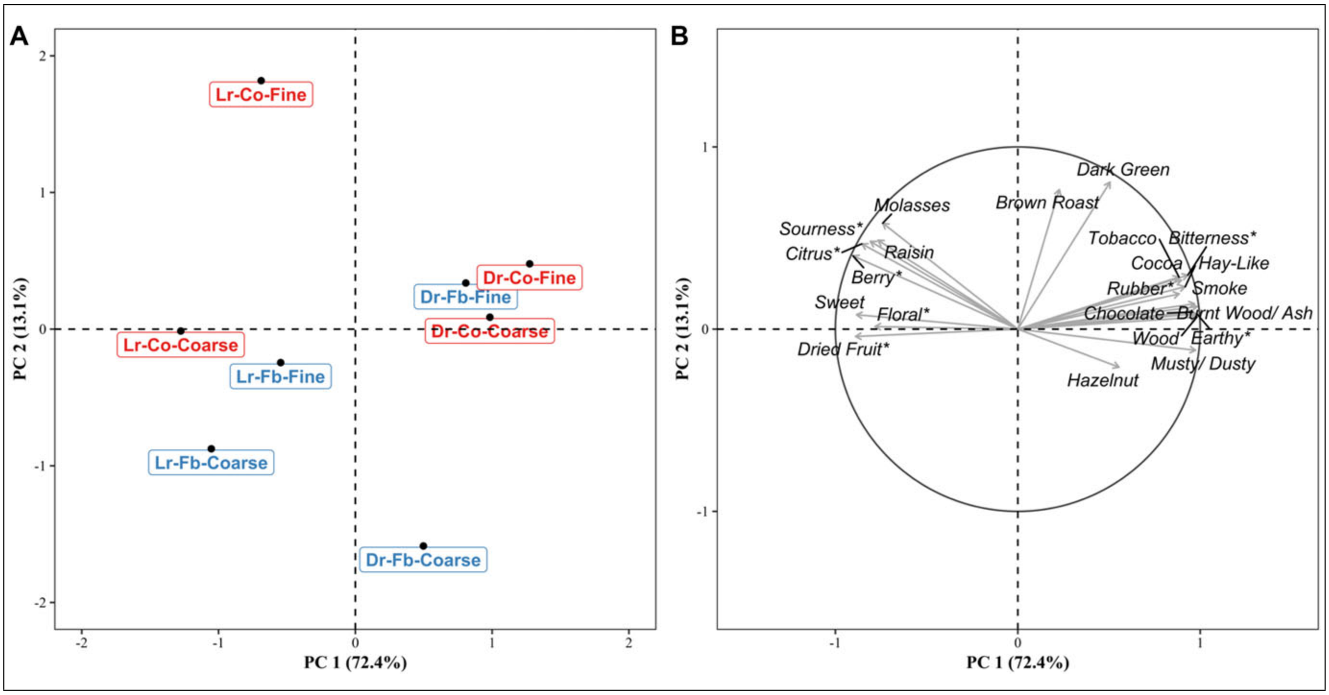

Figure 5–Principal component biplot showing coffees (A) and significant descriptive attributes (B). Treatments codes in panel A are indicated as Lr, light roast; Dr, dark roast; Fb, flat bottom; Co, semi-conical; 3, grind setting 3; 5, grind setting 5.

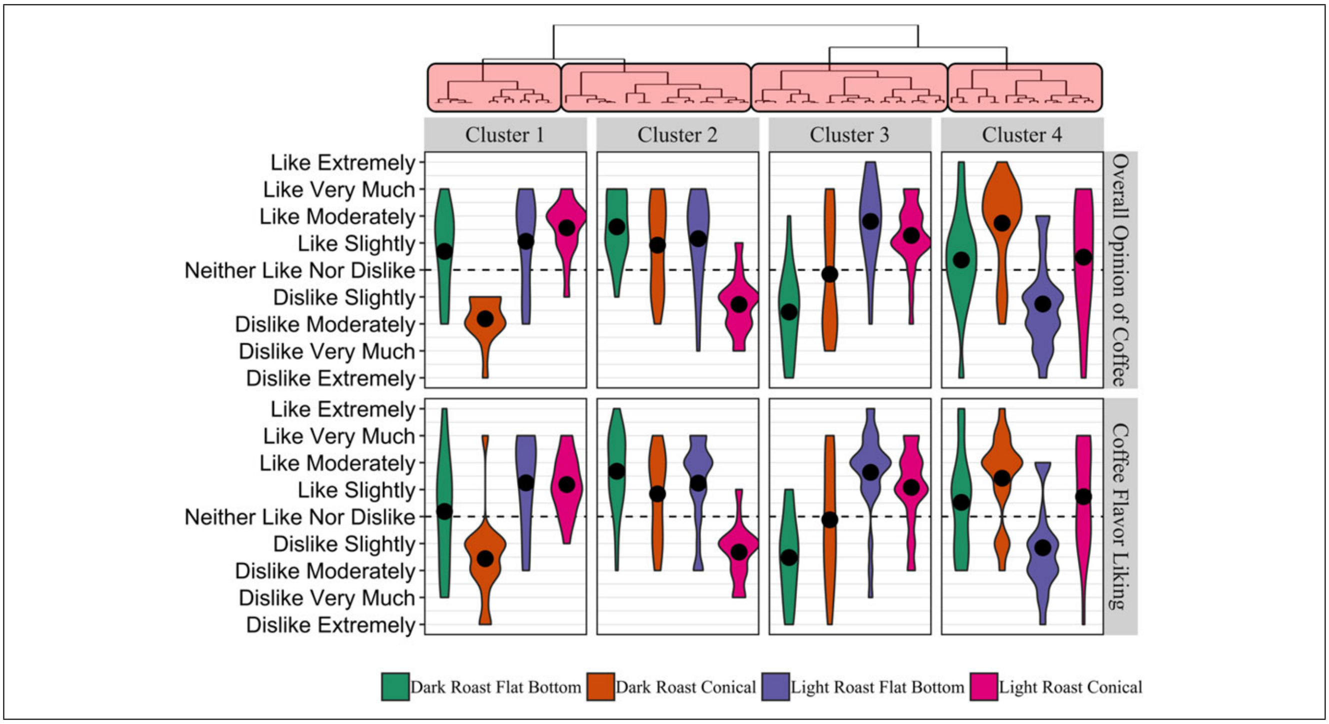

Figure 6–Violin plot showing the distribution of overall opinion of the coffee flavor and overall coffee flavor liking. Mean values for each coffee are indicated by a solid black dot. The violin plots are capped by a dendrogram with cluster segmentation shown by transparent red shading. Cluster membership: Cluster 1, 16 consumers; Cluster 2, 25 consumers; Cluster 3, 25 consumers; Cluster 4, 19 consumers.

by post hoc Tukey's Least Significant Difference (LSD) mean separation. Evaluating coffees brewed at the fine grind within the semi-conical *geometry*, no significant %TDS difference was shown between the two *roasts* (*semi-conical:* Light roast, fine grind and Dark roast, fine grind), although a difference by *roast* was shown for the semi-conical treatments at the coarse grind (*semi-conical:* light roast, coarse and dark roast, coarse). Additionally, significant %TDS differences were not measured between the two grinds for the dark roast coffee (dark roast, fine grind and dark roast, coarse grind).

Table 4–Consumer demographics. Each category is divided by the cluster, with overall study results totaled.

		Age		*Ethnicity*				
Cluster	***N***	**18 to 24**	**25 to 34**	**Asian or Pacific Islander**	**White or Caucasian**	**Hispanic or Latino**	**Black or African-American**	**Other**
1	16	75.0%	25.0%	43.8%	37.5%	12.5%	0.0%	6.3%
2	25	72.0%	28.0%	48.0%	28.0%	20.0%	4.0%	0.0%
3	25	88.0%	12.0%	52.0%	32.0%	8.0%	0.0%	8.0%
4	19	84.2%	15.8%	26.3%	21.1%	42.1%	0.0%	10.5%
total	**85**	**80.0%**	**20.0%**	**43.5%**	**29.4%**	**20.0%**	**1.2%**	**5.9%**

		Gender				*Cups Coffee/Day*			
Cluster	***N***	**Male**	**Female**	**Other**	**Decline to State**	**0 to 1**	**2 to 3**	**4 to 5**	**≥5**
1	16	37.5%	56.3%	0.0%	6.3%	62.5%	37.5%	0.0%	0.0%
2	25	24.0%	72.0%	4.0%	0.0%	56.0%	40.0%	4.0%	0.0%
3	25	52.0%	48.0%	0.0%	0.0%	56.0%	40.0%	0.0%	4.0%
4	19	21.1%	73.7%	0.0%	5.3%	57.9%	42.1%	0.0%	0.0%
Total	**85**	**34.1%**	**62.4%**	**1.2%**	**2.4%**	**57.6%**	**40.0%**	**1.2%**	**1.2%**

		What style of coffee do you prepare at home?							
Cluster	***N***	**French Press**	**Pour Over**	**Aero Press**	**Mokka Pot**	**Espresso**	**Drip**	**Other**	**Not at Home**
1	16	37.5%	25.0%	25.0%	6.3%	12.5%	31.3%	0.0%	25.0%
2	25	28.0%	20.0%	12.0%	8.0%	4.0%	36.0%	32.0%	16.0%
3	25	36.0%	40.0%	16.0%	4.0%	8.0%	16.0%	16.0%	12.0%
4	19	42.1%	10.5%	0.0%	5.3%	10.5%	31.6%	31.6%	5.3%
Total	**85**	**35.3%**	**24.7%**	**12.9%**	**5.9%**	**8.2%**	**28.2%**	**21.2%**	**14.1%**

		What do you normally add to coffee?							
Cluster	***N***	**Brown Sugar**	**White Sugar**	**Artifical Sweetners**	**Milk**	**Cream**	**Non-Dairy**	**Other**	**Nothing**
1	16	0.0%	25.0%	0.0%	25.0%	37.5%	0.0%	6.3%	37.5%
2	25	24.0%	36.0%	16.0%	52.0%	40.0%	20.0%	12.0%	40.0%
3	25	0.0%	24.0%	4.0%	28.0%	28.0%	4.0%	8.0%	64.0%
4	19	10.5%	21.1%	10.5%	42.1%	15.8%	21.1%	10.5%	52.6%
Total	**85**	**9.4%**	**27.1%**	**8.2%**	**37.6%**	**30.6%**	**11.8%**	**9.4%**	**49.4%**

		What style of coffee do you ususlly drink?						
Cluster	***N***	**Drip**	**Instant**	**Espresso**	**Cappuccino**	**Latte**	**Mokka Pot**	**French Press**
1	16	50.0%	6.3%	43.8%	31.3%	68.8%	18.8%	62.5%
2	25	60.0%	24.0%	24.0%	28.0%	52.0%	8.0%	32.0%
3	25	72.0%	20.0%	52.0%	16.0%	40.0%	8.0%	40.0%
4	19	47.4%	31.6%	31.6%	26.3%	47.4%	10.5%	47.4%
Total	**85**	**58.8%**	**21.2%**	**37.6%**	**24.7%**	**50.6%**	**10.6%**	**43.5%**

The %TDS values collected during consumer testing are shown in Figure 8. Significantly different means values were shown among the four coffee treatments evaluated by discrimination testing using a one factor analysis of variance (see Supporting Information A).

Discussion

The experiments reported here aimed to evaluate the sensory quality of coffee brewed using two different brew basket geometries in conjunction with coffee roast level and degree of grinding. All coffees were brewed using a set of identical automatic home brewers with each programed to dispense brewing water at an identical flow rate and temperature. The initial discrimination testing was aimed to establish the relevance of brewing geometry on the sensory perception of drip brewed coffee. The simple hypothesis tested was "with equivalent brewing parameters, does changing the shape of the brewing basket produce a perceptibly different coffee?" Coffee brewed using the semi-conical and flat bottom baskets were compared at two different grinds. Discrimination was shown between the two brewing geometries at the same grind. In contrast, discrimination was not shown when grind size was changed between fine and medium grind with brewing geometry held constant.

The collected %TDS and particle size measures support these observed discrimination results. Coffee brewed using the semi-conical brewing basket produced a higher mean strength coffee as compared to the flat bottom *geometry* (Figure 3 and 9). Additionally, grind also modified TDS as the finer grind produced a significantly higher %TDS for each brewing *geometry*. The difference between the median particle size at the fine and medium grind was 266.0 ± 23.7 μm (SD). This difference provided for a mean TDS increase (in absolute terms) of 0.16 %TDS in the semi-conical and 0.15 %TDS for the flat-bottom brewing basket (Figure 3). These correspond to relative strength increases of 15% and 21%, respectively. The increase in %TDS, as a result of a finer grind, was not sufficient to produce a discriminable difference by triangle

Table 5–Mean drop for each "Just About Right" rating and hedonic rating conbination, by cluster.

How would you rate the intensity of the roast flavor?

			Weak roast flavor		Strong roast flavor	
	Coffee	Cluster	Percentage of cluster (%)	Drop	Percentage of cluster (%)	Drop
Overall liking of the coffee flavor?	Dark Roast Flat Bottom	1	0.0%	0.00	56.3%	−2.01
		2	8.0%	1.15	44.0%	0.38
		3	24.0%	−2.18	68.0%	−3.23
		4	42.1%	−1.60	31.6%	−0.85
	Dark Roast - Semi-Conical	1	6.3%	−2.24	81.3%	−2.62
		2	4.0%	0.76	68.0%	−0.65
		3	12.0%	−1.57	68.0%	−1.89
		4	15.8%	0.43	47.4%	−0.35
	Light Roast Flat Bottom	1	18.8%	−0.47	37.5%	−0.47
		2	36.0%	0.09	24.0%	0.20
		3	24.0%	−0.64	24.0%	−0.30
		4	57.9%	−3.11	31.6%	−2.14
	Light Roast Semi-Conical	1	18.8%	−0.16	37.5%	0.00
		2	28.0%	−2.59	48.0%	−2.75
		3	8.0%	−0.66	28.0%	−1.02
		4	21.1%	−1.16	36.8%	−1.02
Overall opinion of the coffee?	Dark Roast Flat Bottom	1	0.0%	0.00	56.3%	−1.50
		2	8.0%	−0.12	44.0%	−0.16
		3	24.0%	−2.62	68.0%	−3.62
		4	42.1%	−1.99	31.6%	−1.62
	Dark Roast - Semi-Conical	1	6.3%	−3.67	81.3%	−3.44
		2	4.0%	−1.67	68.0%	−1.02
		3	12.0%	−2.33	68.0%	−2.43
		4	15.8%	0.67	47.4%	−0.56
	Light Roast Flat Bottom	1	18.8%	−0.83	37.5%	−0.83
		2	36.0%	0.28	24.0%	−0.33
		3	24.0%	−0.50	24.0%	0.00
		4	57.9%	−3.14	31.6%	−2.67
	Light Roast Semi-Conical	1	18.8%	0.04	37.5%	0.20
		2	28.0%	−2.58	48.0%	−2.88
		3	8.0%	−1.30	28.0%	−0.87
		4	21.1%	−1.55	36.8%	−1.44

How would you rate the intensity of the coffee flavor?

			weak coffee flavor		strong coffee flavor	
	Coffee	Cluster	% of cluster	Drop	% of cluster	Drop
Overall liking of the coffee flavor?	Dark Roast Flat Bottom	1	31.3%	0.46	18.8%	−2.40
		2	12.0%	1.26	36.0%	0.82
		3	36.0%	−1.51	40.0%	−3.24
		4	42.1%	−0.86	21.1%	0.26
	Dark Roast - Semi-Conical	1	6.3%	−2.16	68.8%	−2.89
		2	8.0%	−1.16	48.0%	−0.74
		3	28.0%	−1.16	40.0%	−2.56
		4	26.3%	0.84	31.6%	−0.66
	Light Roast Flat Bottom	1	18.8%	−1.26	18.8%	−1.92
		2	40.0%	−0.29	20.0%	−0.59
		3	16.0%	−0.84	20.0%	−0.59
		4	68.4%	−2.97	15.8%	−1.59
	Light Roast Semi-Conical	1	12.5%	−0.34	12.5%	0.66
		2	28.0%	−2.27	36.0%	−2.06
		3	20.0%	0.76	24.0%	−0.84
		4	21.1%	−1.59	31.6%	−0.51
Overall opinion of the coffee?	Dark Roast Flat Bottom	1	31.3%	0.12	18.8%	−1.22
		2	12.0%	0.45	36.0%	0.45
		3	36.0%	−1.88	40.0%	−3.38
		4	42.1%	−1.01	21.1%	0.12
	Dark Roast - Semi-Conical	1	6.3%	−3.23	68.8%	−3.23
		2	8.0%	0.27	48.0%	−0.89
		3	28.0%	−1.37	40.0%	−2.53

(continued)

Sensory & Consumer Sciences

Table 5–Continued.

		How would you rate the intensity of the coffee flavor?			
		weak coffee flavor		strong coffee flavor	
Coffee	Cluster	% of cluster	Drop	% of cluster	Drop
	4	26.3%	0.77	31.6%	−0.23
Light Roast Flat Bottom	1	18.8%	−1.18	18.8%	−1.85
	2	40.0%	−0.11	20.0%	−1.11
	3	16.0%	−0.01	20.0%	−0.51
	4	68.4%	−2.82	15.8%	−2.18
Light Roast Semi-Conical	1	12.5%	1.11	12.5%	1.11
	2	28.0%	−2.31	36.0%	−2.22
	3	20.0%	1.11	24.0%	−0.55
	4	21.1%	−1.14	31.6%	−1.22

testing between grinds when brewing with either basket geometry. The smallest absolute %TDS difference that did produce discriminable coffees was shown between the flat bottom/fine grind and the semi-conical/medium grind at 0.24% TDS (Figure 3), corresponding to a 28% relative increase in strength. The differences in strength among the four coffees evaluated during discrimination testing are likely playing a key role in the discrimination between each sample. Little information regarding a difference threshold for TDS in brewed coffee is found in the literature. The presented results suggest a minimum absolute difference at 0.24% TDS, but this difference threshold is potentially lower.

A potentially confounding factor is the brew-to-brew variability in %TDS. It is unclear what drove the variability; unlike French press or other full immersion techniques where the grinds and water are well mixed, drip brew coffee intrinsically involves not-well mixed contact between the grinds and the water. In other words, the water moves through the grinds transiently and

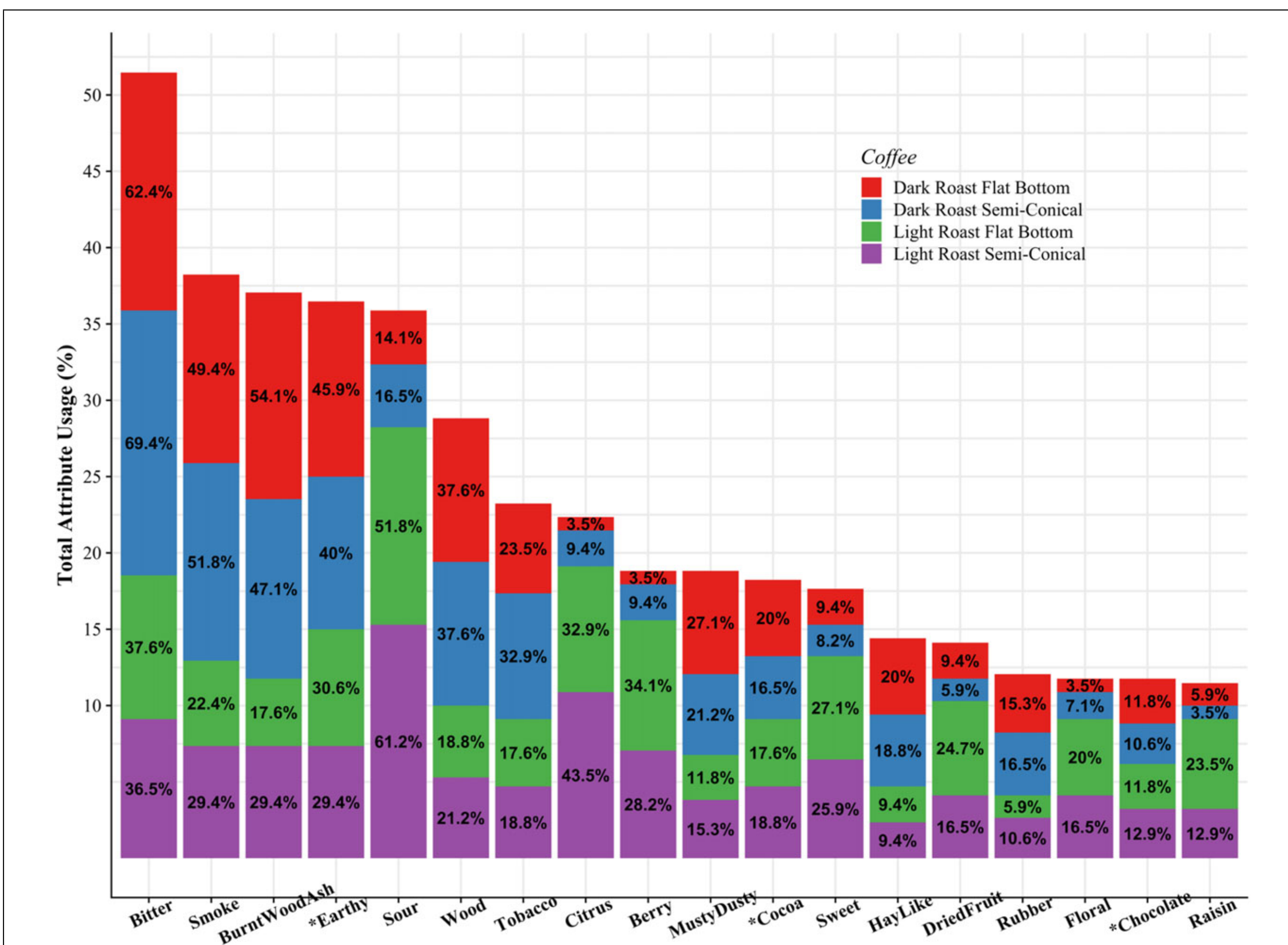

Figure 7–Stacked bar plot showing usage of *Check-all-that-apply* attributes. Each coffee is indicated by position and color. Stared attributes did not significantly differ in consumer usage.

Sensory & Consumer Sciences

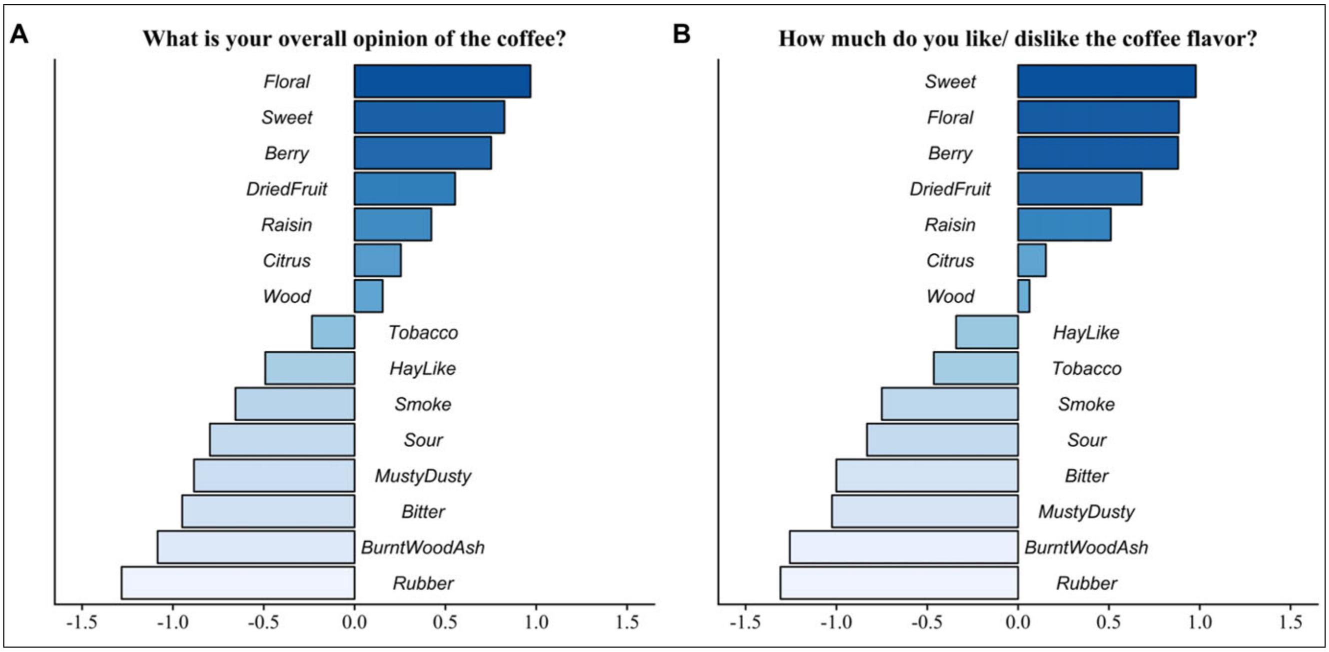

Figure 8–Results of the CATA lift analysis. The values indicate the change in (A) *overall opinion of the coffee* and (B) *overall liking of the coffee flavor* for which the respective attribute was checked, compared to observations when that attribute was not checked.

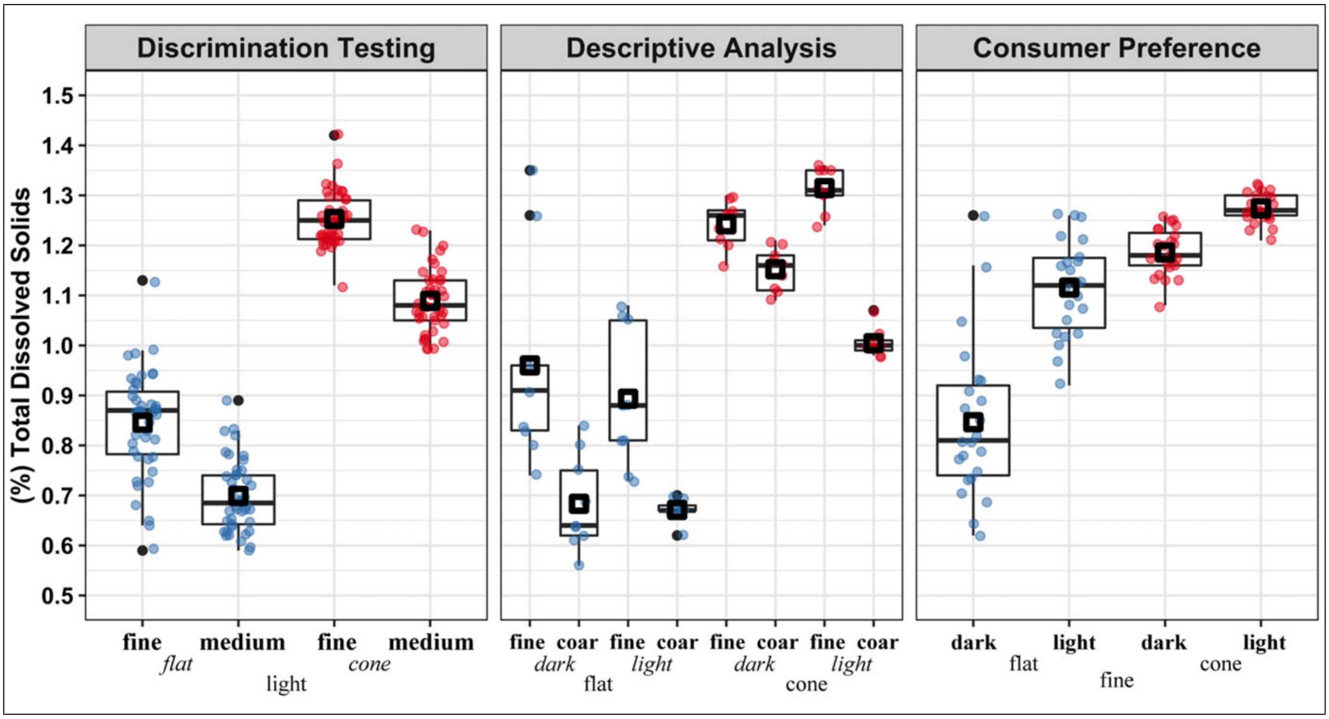

Figure 9–TDS measures for all coffee served during each phase of sensory testing. Treatment means are plotted as a bold square. Discrimination testing ($N = 42$), descriptive analysis ($N = 9$), and consumer preference ($N = 23$).

tends to follow the path of least resistance. One hypothesis for the brew-to-brew variability is that channeling occurred to less or more extent for each brew.

Although these results do show significant discrimination between coffees brewed by each *geometry*, it remains to be determined if two coffees brewed from each *geometry* but altered so as to obtain equal %TDS would still be significantly different in flavor. Under the presented experimental conditions, the brewing parameters for one brewing geometry would require modification (resonance time, flow rate, brewing water temperature, and so on) to produce an equal measured %TDS. These results do demonstrate the impact of brewing geometry to produce different coffees with equivalent brewing conditions (water, temperature, flow, and so on).

Descriptive analysis was used to capture differences in the flavor profile of each coffee induced by the various brewing conditions. The experiment was designed to further evaluate the relationship between brewing *geometry* and *grind*, with the addition of *roast* as a third factor. The evaluated coffees were prepared using either the fine or coarse grind, thus widening the difference in *grind* compared to the protocol for discrimination testing. The results showed *roast* was the most impactful factor on taste and aroma for the eight coffees, with significant differences for 11 of the 26 attributes (Table 3). This *roast* effect was expected, as two different coffees were used, but the factors of *geometry* and *grind* also showed the ability to alter taste and aroma. It should be noted that the difference in median particle size (Figure 2) between the two roasts at the same grind setting was small (for example, 799 compared with 798 μm at the *fine* setting) as compared to the results of changing the grind setting (for example, *fine*-light roast 799 μm compared with *coarse*-dark roast 1115 μm). Thus, sensory differences resulting from the small particle size variation would likely be minimal and not confound comparisons between *roast* and *grind*.

When examining the significant sensory differences related to *grind*, each of the six significant attributes increased at the finer *grind* (Table 3). This increase is only partially related to TDS. The difference in the median particle size (325.6 ± 68.8 μm (SD)) for the dark roast coffee between the two grinds (fine and coarse) did not produce a significant difference in TDS concentration for coffee brewed in the semi-conical basket, while the light roast median particle size difference (404.8 ± 23.7 μm (SD)) did produce a mean difference in TDS concentration in the brewed coffee. This shows that the two coffees (light compared with dark) behaved differently when ground, as each showed a different particle distribution and in turn, flavor differences. Independently, *geometry* impacted few factors but did interact significantly with *roast* and *grind*. These interactions show the importance of *geometry* on the flavor profile of the coffee brew. Six flavor attributes showed an interaction between *geometry* and *roast* (Figure 4), five of these six attributes were then found as preference drivers for consumers.

Using the descriptive sensory and the consumer preference results, the consumer clusters can be characterized. Cluster 1 showed a moderate dislike for the dark roast coffee brewed in the semi-conical basket, indicating that it was too strong in roast flavor. Cluster 3 showed a similar dislike for the dark roast coffee brewed with the flat-bottom basket. In each case, the consumers were likely responding negatively to the *bitter* and *burnt wood/ash* flavors. Clusters 2 and 4 showed a dislike for *sourness* and *citrus* flavors. Within the consumer study, these four terms (*bitterness*, *burnt wood/ash flavor*, *citrus flavor*, and *sourness*) were heavily used (Figure 7) and were associated with dislike. For example, *bitterness*, which was picked by 51.5% of the consumers (Figure 7), was associated with a 1 point. decrease for each liking question. *Burnt wood/ash* shows a similar trend with 37.1% selection. Together, *burnt wood/ash* and *bitterness* were the strongest (negative) drivers of acceptance in the consumer study.

Conclusions

This study aimed to evaluate the effect of brewing geometry on drip-brewed coffee. Two basic brew basket shapes were evaluated (flat-bottom and semi-conical). Grind and roast were varied to evaluate the interaction of these factors within each brewing geometry. A 25% difference in median particle size was not discernable when evaluated within a given brewing geometry, but discrimination was shown when comparing between geometries. The semi-conical brew basket produced coffee of a significantly higher %TDS then the flat-bottom brew basket, and we hypothesize that %TDS was a key driver of discrimination. Among all four coffees evaluated by triangle testing, a %TDS difference threshold of 0.24 was found. The accuracy of the difference threshold is potentially related to the brew-to-brew variability, so future testing might benefit from methods aimed at using different brewing parameters followed by artificial means of equalizing %TDS (for example, dilution with hot water).

Descriptive analysis explored the relationship between grind and roast for each brewing geometry for 26 unique sensory attributes. Factor analysis showed roast as the primary source of variation, significantly altering 11 attributes independent of brewing geometry and grind. Geometry, independent of the other two factors, altered three attributes, while grind influenced six attributes. The effect of grind was unidirectional; with smaller median particle size, all of the six significant attributes increased in intensity. Grind acted to increase or decrease these specific attributes, leading to the need for future studies evaluating the relationship between extraction and particle size. Geometry, although not as significant a driver compared to very different roast levels and a large difference in grind size, still showed unique interactions. This result is critical for assessing what brewing method to employ for specific market segments. With future work evaluating brewing methods, %TDS as a factor should be controlled. Brews of equivalent %TDS produced from a flat-bottom and conical basket, perhaps prepared by altering flow rate *in situ* or via *post facto* dilution, potentially would not produce similarly discriminable brews. Nonetheless, the results presented here clearly demonstrate that basket geometry strongly affects the flavor profile and consumer acceptance of drip brewed coffee.

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Author Contributions

S. C. Frost designed the study, collected the data, interpreted the results, and drafted the manuscript. W. D. Ristenpart secured funding and assisted in study design and final manuscript preparation. J.-X. Guinard assisted in study design, interpreted the results, and edited the manuscript.

Conflict of Interest

Funding was provided by the Specialty Coffee Association with underwriting by Breville Corporation.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Supplemental A. Total Dissolved Solids (% TDS), F-ratios.

Supplemental B. Percent Extraction, alternative to Figure 9.

Supplemental C. ANOVA by specific coffee.