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ORIGINAL ARTICLE

Sensory and Consumer Sciences

A new Coffee Brewing Control Chart relating sensory properties and consumer liking to brew strength, extraction yield, and brew ratio

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Abstract: The classic Coffee Brewing Control Chart (BCC) was originally developed in the 1950s. It relates coffee quality to brew strength and extraction yield, and it is still widely used today by coffee industry professionals around the world to provide guidance on the brewing of coffee. Despite its popularity, recent experimental studies have revealed that sensory attributes and consumer preferences actually follow much more complicated trends than those indicated by the classic BCC. Here, we present a methodology to synthesize the results of these recent studies on drip-brewed coffee to generate new versions of the BCC: a new Sensory BCC that displays a broad array of statistically significant sensory attributes across typical total dissolved solids and percent extraction ranges, a new Consumer BCC that highlights the existence of two preference clusters with different likes and dislikes across those ranges, a new Sensory and Consumer BCC that combines both sensory descriptive and consumer preferences on the same chart, and a more streamlined BCC that omits consumer preferences and focuses on the overarching sensory descriptive trends. The new BCCs provide more accurate insight on how best to brew coffee to achieve desired sensory profiles.

KEYWORDS
coffee brewing control chart, drip coffee, sensory profile, descriptive analysis, preference mapping, response surface methodology

Practical Application: Through the manipulation of yield and extraction parameters, the new Sensory and Consumer Coffee Brewing Control Chart presented here can be used by brewers of drip coffee to design coffees with specific sensory profiles and match the preferences of different consumer types.

1 | INTRODUCTION

The enjoyment of coffee worldwide is driven primarily by its sensory quality (Samoggia & Riedel, 2018), which in turn depends on the variety, origin, terroir, postharvest processing, roasting, and brewing of the coffee through a complex mixture of flavor compounds that include carbohydrates, acids, lipids, proteins, antioxidants, and volatile aroma compounds (Clarke & Macrae, 1985; Frost et al., 2022; Seninde & Chambers, 2020; Sunarharum et al., 2014; Yeager et al., 2021). In particular, the rise of "specialty" coffee has driven expanding research into coffee flavor and brewing in the past decade (Allhoff et al., 2011; Mestdagh et al., 2017; Sunarharum et al., 2014). While many factors contribute to the overall sensory profile of coffee, brewing is a key step that can dramatically influence the taste and flavor of the beverage regardless of the care put into growing, processing, and roasting the coffee. As such, it is important to understand how the sensory profile relates to the brewing process to optimize coffee quality and maximize consumer satisfaction.

Key metrics were established early on to characterize the quality of brewed coffee. A seminal publication titled *The Soluble Solids in Beverage Coffee as an Index to Cup Quality* was released in 1957 by Ernest E. Lockhart from the Coffee Brewing Institute. This publication related the quality of brewed coffee to two key metrics: the "brew strength," which is the mass fraction of soluble solids in the brew, commonly referred to as the total dissolved solids, or TDS, and the "extraction yield," which is the mass fraction of soluble solids removed from the coffee grounds, commonly referred to as the percent extraction or PE (Lockhart, 1957). These quantities are linked via the conservation of mass to the brew ratio $R_{brew} = m_w / m_g$ of water to coffee grounds, following the relationship:

$$PE = \frac{TDS}{1 - TDS}(R_{brew} - R_{abs}),$$

where $R_{abs} \approx 2.1$ is the "absorption ratio" or "liquid retention ratio" of water retained in the spent moist grounds (Ristenpart & Kuhl, 2021; Liang et al., 2021). Note that brew ratio is often expressed in terms of the mass of coffee grounds per mass of water, or less precisely in terms of the mass of coffee grounds per volume of water, which necessitates assumptions about the density of the water. The three quantities—TDS, PE, and R_{brew} —were combined by Lockhart in the classic "Coffee Brewing Control Chart" or BCC (Lockhart, 1957; cf. Figure 1). The horizontal axis represents PE; the vertical axis represents TDS; and the diagonals represent specific values of the brew ratio, expressed here in grams of coffee grounds per liter of water. To this day, the chart serves as the basis for vocational

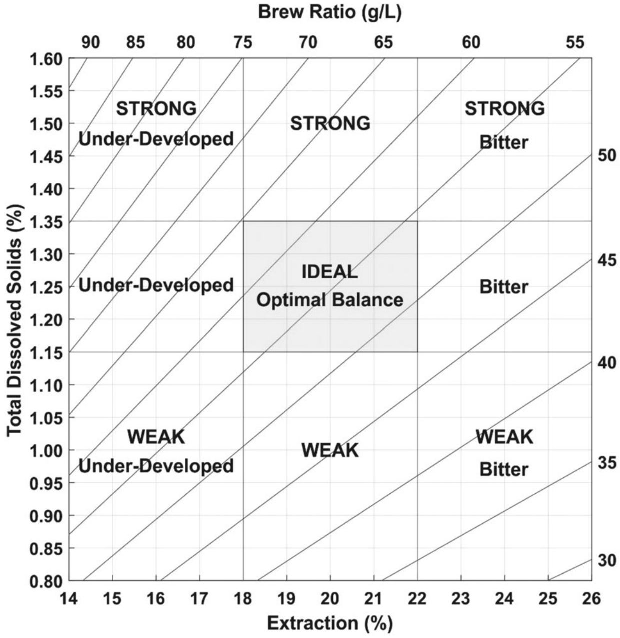

FIGURE 1 The Coffee Brewing Control Chart, adapted from *The Coffee Brewing Handbook* (page 9), by T.R. Lingle (2011), Specialty Coffee Association of America.

training in the coffee industry and features prominently in the Coffee Brewing Handbook published by the Specialty Coffee Association (Lingle, 2011). The chart highlights the presence of certain sensory attributes or features and the notion of an "ideal cup" as a function of TDS, PE, and brew ratio of drip-brewed coffee (Figure 1).

The classic BCC is an iconic tool that is used by coffee professionals and home brewing aficionados the world over to manipulate brewing parameters in order to deliver a specific sensory profile and that "ideal" cup of coffee. Despite its widespread use, the classic BCC has shortcomings. It only shows a few "attributes" (i.e., "bitter," "underdeveloped," "ideal") and their relative intensity ("weak," "strong"). Furthermore, it mixes descriptive ("what does it taste like, and how intensely?"), hedonic ("do I like it?"), and quality ("Is this a high-quality coffee?") sensory concepts. It is unclear both from the chart itself and its source material which consumers (or experts) find coffee in the center of the chart to be "ideal." Perhaps most importantly, the chart ignores the wide variety of flavor attributes that may be found in coffee, or even those common to most coffees (sour, burnt, roasted, to name a few). The World Coffee Research Sensory Lexicon (2017) and the Coffee Taster's Flavor Wheel (Spencer et al., 2016) list more than 100 flavor attributes that have been found in black coffee, including desirable ones (i.e., dark chocolate, berry, caramel) and those considered defects (i.e., medicinal, rubber, moldy). Overall, knowledge of flavor chemistry, engineering, sensory analysis, and other fields relevant to coffee has grown since the Coffee Brewing Institute's initial research, and as such, any BCC should reflect the latest science and knowledge on coffee quality in relation to brewing parameters.

Many recent studies have documented the sensory attributes of drip brew coffee as a function of a number of parameters, including, for example, basket geometry (Frost, Ristenpart, & Guinard, 2019), brew and consumption temperature (Adhikari, Chambers, & Koppel, 2019; Chapko & Seo, 2019), or brew method (Gloess et al., 2013). These studies, however, did not systematically assess brews across the BCC's parameters of TDS, PE, and brew ratio.

Over the past several years, we conducted sensory and consumer research to fill this knowledge gap. Through the manipulation of various brewing parameters, such as grind size, flow rate, and temperature, we drip brewed coffees that systematically varied in TDS and PE across the BCC. The first study (Frost et al., 2020) was a 3^3 factorial design covering three levels of TDS (1%, 1.25%, and 1.5%), three levels of PE (16%, 20%, and 24%), and three roast levels (light, medium, and dark), for 27 coffees in total. A trained descriptive analysis panel measured the intensity of 30 sensory attributes in all brews. The second descriptive analysis study (Batali et al., 2020) was also a 3^3 factorial design with the same levels of TDS and PE, but instead of roast level, brew temperature was set at 87, 90, or 93°C, for another 27 samples evaluated by another trained descriptive analysis panel for the intensity of 33 sensory attributes. In the third study (Cotter et al., 2021), those same 27 brews were also evaluated for liking on the 9-point hedonic scale (Peryam & Pilgrim, 1957), adequacy of select attributes on just-about-right scales, and check-all-that-apply among select attributes by untrained consumers of black coffee. Full information on the studies' methodology can be found in the three cited papers. All research was reviewed and approved for the use of human subjects by the UC Davis Institutional Review Board (IRB# 1082568) and informed consent was obtained from each subject prior to their participation in the studies. Together, the three studies yielded a total of 324 chemical or physical measurements, 32,076 sensory descriptive measurements, and 3186 consumer liking measurements, with trends summarized in a total of seven tables and 28 figures that included 64 response surfaces generated by response surface methodology. Although this represents a wealth of data, the sheer volume of data obfuscates key trends and complicates interpretation for the coffee industry.

The main goal of this paper is to integrate the results of those three studies into new and updated versions of the classic BCC. We present a new Sensory and Consumer Brewing Control Chart that reflects the integration and culmination of our comprehensive sensory and consumer research on the effects of brewing variables on the sensory quality and consumer acceptance of drip brew coffee (Batali et al., 2020; Cotter et al., 2021; Frost et al., 2020). It features two components—a sensory component, with those key sensory attributes that vary across the chart; and a consumer or hedonic component that shows the areas of maximum consumer liking, as functions of TDS, PE, and brew ratio. We also propose three other integrated charts: a new Sensory Brewing Control Chart that features only the sensory component of the new chart; a new Consumer Brewing Control Chart that features the consumer or hedonic component of the new chart; and a Streamlined Brewing Control Chart, with only the main sensory attributes in the new chart and a reference to the "ideal" standard in the classic BCC.

2 | METHODOLOGY

2.1 | A new Sensory Brewing Control Chart and its streamlined version

Our first goal was to synthesize the sensory descriptive data to highlight which sensory attributes are expressed most fully in the various areas of the BCC as a function of TDS, PE (and brew ratio). A key challenge is that each sensory attribute (e.g., bitter, sweet, citrus) had its own response surface across TDS and PE (cf. Figures 8–10 in Frost et al., 2020 or Figure 6 in Batali et al., 2020), so that superposition of multiple attributes onto a single graph would yield a confusing hodgepodge of contours.

Instead, to feature the key trends, we opted to highlight in which direction of the chart specific sensory attributes can be maximized, and to indicate the magnitude of change via font size. To do this, we included specific sensory attributes from the Frost et al. (2020) and Batali et al. (2020) studies in the sensory chart based on the following six criteria:

- An attribute mean intensity of 20–50 on the 100-point descriptive analysis scale we used
- A statistically significant variation of the attribute across the BCC (vs. TDS, PE, or ideally, both) as per analysis of variance
- An attribute vector with high loadings on "significant" principal components in a principal component analysis of descriptive analysis data (indicative of significant contribution to the variance in the sensory profiles of the coffees)

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- A significant response surface model fit for the attribute versus TDS and PE (as a flat plane or a dome slice)
- A significant (Pearson's Product-Moment) correlation between the attribute mean intensity and TDS and/or PE
- The attribute be a significant driver of consumer liking for the coffees as per external preference mapping (Cotter et al., 2021)

A streamlined version of the new Sensory BCC was also developed that includes only the main sensory attributes in the new Sensory BCC, and displays them on the background of the classic BCC for familiarity and ease of use.

2.2 | A new Consumer Brewing Control Chart

Our second goal was to display the preferences of a population of black coffee consumers as a function of TDS, PE, and brew ratio. In our study of black coffee consumer liking of coffees brewed across the BCC (Cotter et al., 2021), we uncovered two preference segments by cluster analysis (i.e., *preference clustering*), that is, two groups of coffee drinkers with different likes and dislikes. Our new Consumer Brewing Control Chart displays the response surfaces relating liking to TDS and PE for those two preference segments as a three-dimensional space.

2.3 | A new Sensory and Consumer Brewing Control Chart

Our third goal was to combine the two charts—the new Sensory BCC and the new Consumer BCC into one—a new Sensory and Consumer Brewing Control Chart that would display both sensory attributes and patterns of consumer liking as a function of TDS, PE, and brew ratio. This was done by projecting the two consumer segments' liking response surfaces of the new Consumer BCC onto the new Sensory BCC with its sensory attributes in a two-dimensional display.

3 | RESULTS

3.1 | The new Sensory Brewing Control Chart

The attributes that met the criteria for inclusion in the new Sensory Brewing Control Chart were: bitter, acid/sour, citrus, roasted, viscous/thick, astringent, 'sweet', burnt/ash, black tea, dark greens, berry, and dried fruit. The new Sensory BCC is shown in Figure 2.

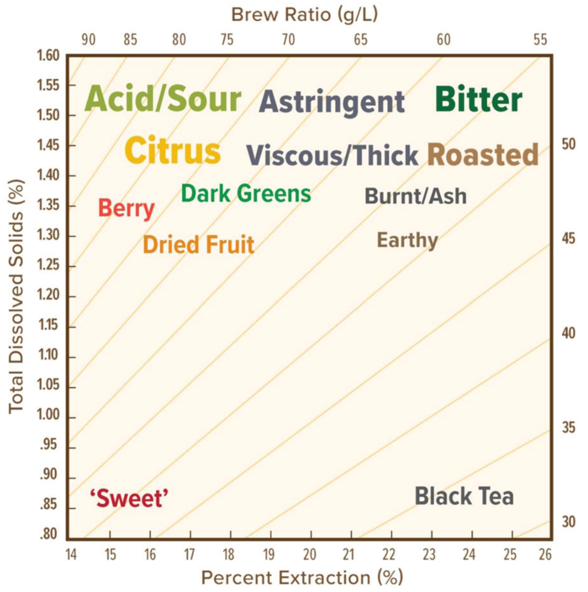

FIGURE 2 The new Sensory Brewing Control Chart showing the main coffee sensory attributes in drip black coffee as a function of TDS, PE, and brew ratio. Place the coffee on the chart using its TDS, PE, and brew ratio coordinates, and its expected sensory attributes will be those found in that area of the chart. For example, acid/sour, citrus, and red fruit notes would be expected in a coffee with high TDS and low PE, whereas bitterness, astringency, and roasted notes should prevail in a coffee with high TDS and high PE. Abbreviations: PE, percent extraction; TDS, total dissolved solids.

The location of each sensory attribute on the chart corresponds to its maximum expression according to the response surfaces (plane or dome slice) generated in Frost et al. (2020) and/or Batali et al. (2020). The intensity of some attributes (i.e., bitterness, acidity, astringency, earthy, rubber) was measured in both descriptive analyses, whereas the intensity of others (i.e., sweetness, black tea, dark greens) was only measured in one.

The color in which the sensory attribute appears on the chart is indicative of cross-modality matching of tastes with colors (Guinard et al., 1996), or represents the natural color of the item named with the attribute (i.e., green for dark greens, and red for berry). Its font size in turn is indicative of the intensity of the sensory attribute on the 100-point descriptive analysis scale we used. As a result, bitterness, roasted flavor, and acidity/sourness, for example, appear in large fonts, whereas dark greens and berry are shown in small fonts (Figure 2).

The attribute 'sweet' is written with single quotation marks as it most likely does not represent true sweet taste but rather a 'sweet' flavor impression that is perceived in association with 'sweet' aromatics, and in contrast with,

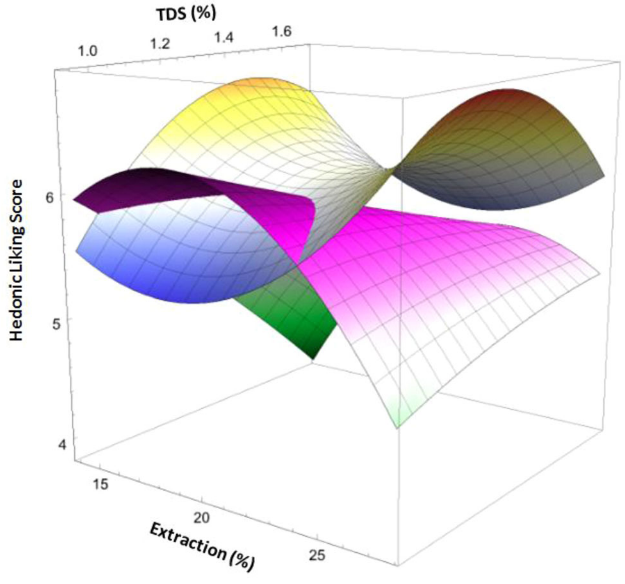

FIGURE 3 The new Consumer Brewing Control Chart showing the response surfaces of two consumer preference segments (Cluster 1 in pink, and Cluster 2 in green) relating their degree of liking of the 27 coffees in the design on the 9-point hedonic scale to TDS and PE (Cotter et al., 2021). Consumers in the first cluster will like most coffees with low TDS and medium PE corresponding to the top of the pink, dome-shaped response surface, whereas consumers in the second cluster will like best either coffees with medium TDS and low or high PE at either edge (yellow or red) of the saddle-shaped response surface. Abbreviations: PE, percent extraction; TDS, total dissolved solids.

or in the absence of, bitterness and to a lesser extent, acidity/sourness. Indeed, sweet sugars (mono and disaccharides) are not typically present at concentrations above the sweet taste recognition threshold in brewed coffee (Batali et al., 2020).

3.2 | The new Consumer Brewing Control Chart

Our new Consumer BCC is shown in Figure 3. It displays the response surfaces relating liking to TDS and PE for the two preference segments we uncovered in our study of consumer liking of black coffees brewed across the BCC (Cotter et al., 2021).

For the first preference segment, representing the majority of consumers (57%), liking versus TDS and PE was best fitted by a (slice of a) dome response surface (shown in pink to purple in Figure 3) which went up as TDS decreased and peaked at 18% extraction. Consumers in the first preference segment liked best the coffees in the lower left corner of the BCC—those with low TDS and low to medium PE.

If we examine our new (sensory) BCC, we may conclude that the consumers in this segment liked sweet coffees best, as their peak liking is colocated with the 'sweet' attribute. An equally accurate or realistic characterization of their preferences, however, is that they disliked bitter coffee, and acid/sour coffee, as their peak liking is located exactly opposite the bitter attribute and away from the acid/sour attribute (and their liking response surface is the exact reverse of the bitterness response surfaces we obtained in Frost et al., 2020 and Batali et al., 2020).

The second preference segment, with 43% of the consumers, produced a more complex pattern of liking versus TDS and PE, represented by a saddle-shaped response surface with two areas of maximum liking at each end of the saddle. This segment liked equally two distinct types of coffees, with low PE and medium to high TDS on the one hand, and high PE and medium TDS on the other hand, at the front and back of their saddle (Figure 3).

If we refer back to our new Sensory BCC, those coffees liked equally by the second preference segment would present acid/sour, citrus, berry, and dried fruit sensory attributes on the one hand, and roasted, burnt/ash, thick, and black tea sensory attributes on the other hand (at the back and front of their saddle, respectively).

To further examine the impact of specific sensory attributes on consumer preferences, we conducted a Penalty/Lift Analysis relating degree of liking by the two preference clusters to the presence of specific sensory attributes (Figure 4). It provides further insights into the respective preferences of the two clusters in terms of which sensory attributes might drive their liking for drip coffee, either positively or negatively. Indeed, and even though the two clusters appear mostly aligned on which sensory attributes drive their liking (i.e., the majority of green and red bars on the graph have similar directions and sizes), Cluster 1 was more positively impacted by tea/floral and citrus attributes and more negatively impacted by sour and burnt attributes than Cluster 2. In addition, Cluster 2 was also more positively impacted by roasted, dark chocolate, and nutty attributes, and more negatively impacted by paper/woody, green vegetables, and rubbery attributes than Cluster 1. These trends largely align with the respective locations of the two clusters' response surfaces on the new Consumer BCC (Figure 3).

3.3 | The new Sensory and Consumer Brewing Control Chart

We can now combine the two charts presented above into one new, three-dimensional Sensory and Consumer Brewing Control Chart which is shown (in two dimensions) in Figure 5. It projects the areas of greater liking for the two

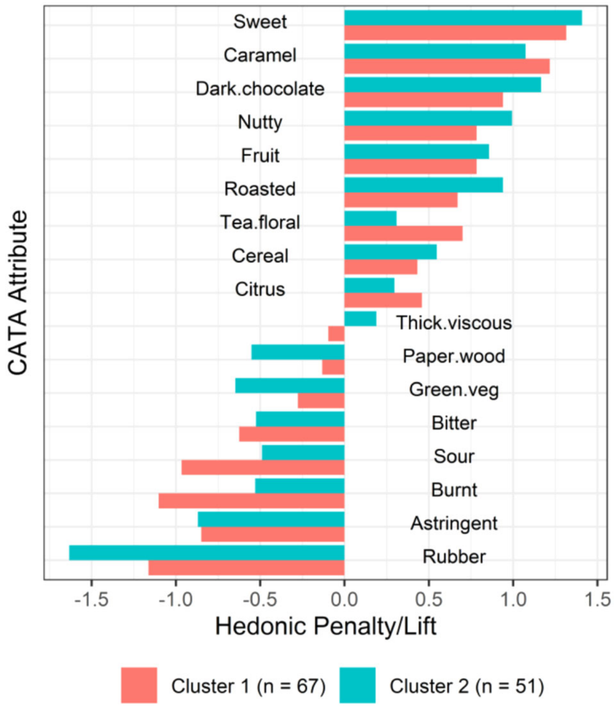

FIGURE 4 Penalty/Lift Analysis relating degree of liking by the two consumer preference clusters identified in Cotter et al. (2021) to the presence of specific sensory attributes in drip coffee.

preference segments we identified onto the Sensory BCC with its sensory attributes. The apex of the dome response surface for the first preference segment coincides with the 'sweet' attribute and is away from both the bitter and acid ones. In contrast, there are two areas of higher liking in the saddle response surface of the second preference segment, one corresponding to acidic and fruity coffees and the other to (dark) roasted, somewhat bitter and black tea like, thick and ashy coffees.

We propose that this new Sensory and Consumer BCC replace the classic BCC and be used by brewers of drip coffee to obtain specific sensory profiles and/or closely match the preferences of different consumer types.

3.4 | Streamlined version of the new Sensory Brewing Control Chart

A strength of the new Sensory and Consumer BCC in Figure 5 is that it clearly illustrates how the classic "ideal" range does not pertain to all consumers. However, the consumer preference data displayed here are based on a study of primarily young adult consumers in Northern California. It is well established that consumer preferences vary significantly around the world with demographics, such as gender, age and income, psychographics, and coffee consumption habits (Arnot et al., 2006; Bookman, 2013; Czarniecka-Skubina et al., 2021; Spinelli et al., 2017). Accordingly, a version of the BCC that focuses solely on sensory descriptive attributes, independent of variable consumer preferences, was desirable. Likewise, to simplify the training of new workers in the coffee industry, it was sensible to minimize the number of distinct sensory attributes presented on the chart and thus focus attention on the most important ones.

A 'streamlined' version of the BCC that satisfies these criteria is presented in Figure 6. For the sake of clarity, a maximum of two descriptive attributes were placed in each of the four corners, and consumer preference trends were omitted entirely. Each corner of the chart was shaded with a distinct color, consistent with the color choices in the detailed Sensory BCC (Figure 2), with a gradient in intensity to denote qualitatively the corresponding increase in the respective sensory attributes. Because the "ideal" range originally developed by Lockhart has been taught to the coffee industry for decades, the streamlined version of the BCC includes a gray box to denote this range; to avoid confusion, however, we label this box the "classic standard" rather than "ideal," since it is unclear what consumer segments found those brewing conditions ideal. Note that in this version, we specified the brew ratio in terms of the mass of water per coffee grounds, rather than the mass of coffee grounds per volume of water; an equivalent version using the mass of coffee per volume of water is readily constructed.

4 | DISCUSSION

4.1 | Sensory and Streamlined Brewing Control Charts

The Classic Brewing Control Chart (Lockhart, 1959) has been used for over 60 years by drip coffee brewers to brew supposedly "ideal" coffee by staying away from the four corners of the chart and their "weak," "strong," "under-developed," or "bitter" characteristics. The new Sensory Brewing Control Chart we propose here displays a much more comprehensive, appropriate, and relevant set of sensory descriptors for coffee in relation to yield and extraction parameters. The streamlined version displays the same information with a reduced set of key sensory attributes, and it retains the look and feel of the original chart for ease of transition and use by coffee professionals who are used to working with the classic BCC.

Our new Sensory BCC speaks to the expression of key coffee sensory attributes as a function of TDS and PE only. It does not illustrate the effects of variety, origin, roast, and brewing variables, other than the ones in our experimental designs, on the sensory quality of coffee.

The location of each attribute on the chart is indicative of its maximum level of expression as a function of

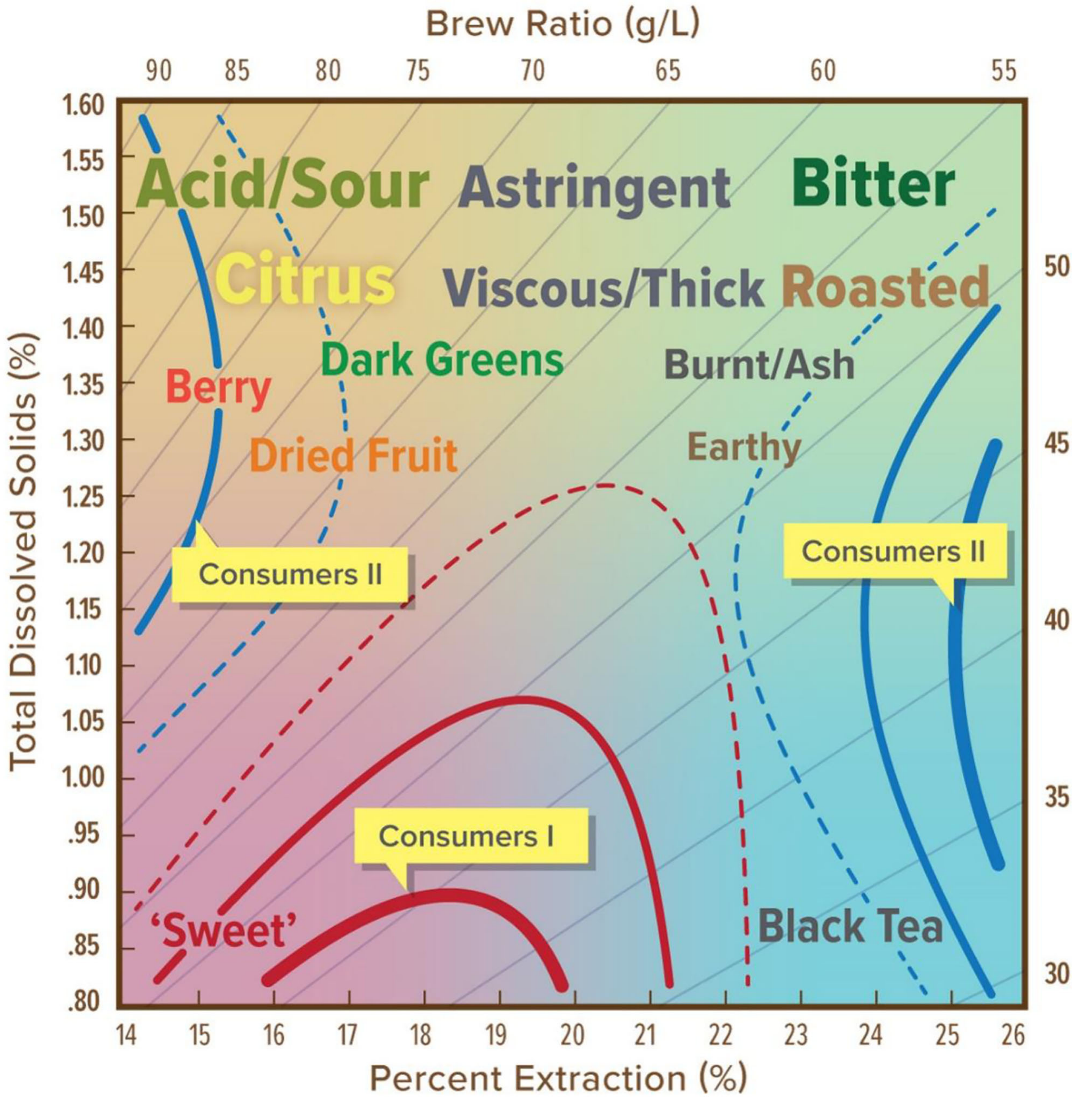

FIGURE 5 The new Sensory and Consumer Brewing Control Chart showing both key coffee sensory attributes and the response surfaces of two consumer preference segments (Consumers I and Consumers II) as a function of TDS, PE, and brew ratio. By placing a coffee on the chart using its TDS, PE, and brew ratio coordinates, one can find out which sensory attributes it should have, and how the two types of consumers in our study might like it. Abbreviations: PE, percent extraction; TDS, total dissolved solids.

TDS and/or PE, but to be expressed, the attribute must be present in the coffee to begin with. The coffees we investigated in the studies from which we developed the Sensory and Streamlined BCCs spanned a wide range of origins, roasts, and drip brewing parameters. It follows that the coffees in those designs must have covered the spectrum of sensory qualities in drip coffee well, and that those Sensory and Streamlined BCCs should be fairly definitive instruments.

4.2 | The new Consumer Brewing Control Chart

The existence of two distinct preference clusters in our study of consumer liking of coffees brewed across the BCC with black coffee drinkers (Cotter et al., 2021) dismisses the "ideal," one-size fits all, representation of consumer liking in the Classic Brewing Control Chart. But had we

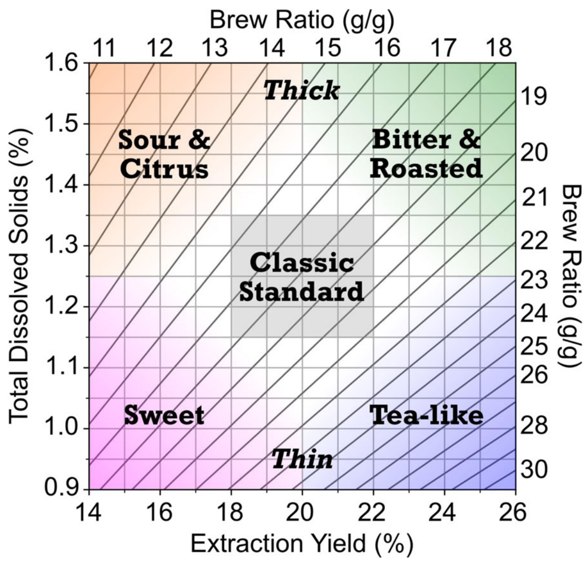

FIGURE 6 Streamlined version of the new Sensory Brewing Control Chart, showing select coffee sensory attributes as a function of TDS, PE, and brew ratio, and the location of the ideal coffee standard from the classic BCC (Figure 1) as "Classic Standard." Place the coffee on the chart using its TDS, PE, and brew ratio coordinates, and its expected sensory attributes will be those found in that area of the chart. Abbreviations: PE, percent extraction; TDS, total dissolved solids.

looked for the average liking across the entire population we tested, we would indeed have found that maximum liking occurred close to the "ideal" point on the classic BCC (cf. Figure 8c in Cotter et al., 2021). But that averaging would have meant ignoring preference segmentation and thus been an incorrect conclusion. The "ideal" coffee represented in the classic BCC, therefore, is misleading, and quite possibly, inaccurate. Through the advent of preference mapping as a technique for understanding the preferences of consumers for a product category, consumer product companies have come to abandon the notion that there exists an ideal product that every consumer will like. Indeed, and regardless of the product category, most preference mapping studies uncover multiple preference segments.

The two preference segments we identified in our study of consumer preferences for drip brew coffee, and included in the Consumer BCC as a result, are from a population of young Northern California adults who consumed black coffee. A study with other black coffee drinkers somewhere else in the world could produce a different preference segmentation, possibly with more than two preference segments and possibly with different response surfaces relating those segments' liking to TDS and PE.

Consumers in the first preference segment liked best the coffees in the lower left corner of the BCC—with low TDS and low to medium PE, or coffees characterized by low bitterness and acidity and some perception or illusion of sweetness (from the presence of 'sweet' aromatics and the absence of notable bitterness and acidity). We conclude that this first preference segment was representative of the typical or average coffee drinker, and we speculate that it would likely be found in any study of consumer preferences for coffee. We further speculate that this preference segment would be more likely to drink their coffee with milk and/or sugar if given the option, to mitigate any notable bitterness and acidity.

The second preference segment liked equally coffees with acid/sour, citrus, berry, and dried fruit sensory attributes on the one hand or coffees with roasted, burnt/ash, thick, and black tea sensory attributes on the other hand, at the back and front of their saddle, respectively. This was unexpected and may seem odd, but it occurs to us that those areas of the BCC match the flavor profiles of high-quality specialty coffees and typical espresso blends, respectively, and may speak to a preference segment of more experienced and neophilic coffee drinkers, who were familiar with a broader range of coffees. We also speculate that depending on the greater prevalence of specialty coffee or espresso in their environment, consumers in this preference segment would tip their saddle backward or forward, respectively, in favor of specialty coffees' acidic, fruity, and 'sweet' flavor profiles or more typical espresso sensory attributes, such as dark roast and bitterness.

Whereas the Sensory BCC is a definitive tool in the sense that the sensory attributes that are displayed in it, and the way they are displayed, are set, based on the criteria we adopted for their inclusion and location, the Consumer BCC is but one version of the chart, one that is based on the likes and dislikes of a population of Northern California consumers of black coffee. We would certainly encourage the investigation of the preference segmentation and specific likes and dislikes of other populations of drip coffee drinkers around the world.

4.3 | The new Sensory and Consumer BCC

The field of sensory and consumer science has strived for years to develop techniques that provide an understanding of the sensory drivers of consumer liking through the use of advanced sensometrics. In that sense, preference mapping represented a major advance in our field as it not only uncovered preference segmentation and sensory drivers of liking for the uncovered segments, but also provided user-friendly graphical representations of the outcomes in the form of dendrograms of consumers, internal preference maps of products and consumers, and most actionable, external preference maps of products, consumers, and sensory attributes (Greenhoff & MacFie, 1994; Guinard et al., 2001). And before it, response surface methodology offered a means of relating consumer liking to the concentration of specific ingredients or the intensity of specific sensory attributes through complex regressions, and again powerful graphical representations of these relationships whether they were simple or complex (Giovanni, 1983). The present paper builds on those techniques and offers new graphical representations of the way sensory attributes and consumer liking may relate to TDSs, PE, and brew ratio in coffee. The Sensory and Consumer BCC displays both sets of relationships on the same graph, and thus affords brewers of drip coffee the ability to design coffees with specific sensory profiles for different consumer types through the manipulation of yield and extraction parameters.

In the same way that different versions of the Consumer BCC could and should be developed for different populations of drip black coffee drinkers around the world by representing the liking response surfaces of uncovered preference segments for those populations, they could then be projected onto the Sensory BCC for the generation of other Sensory and Consumer BCCs.

The BCCs presented here show how sensory attributes and consumer preferences are expressed as a function of TDS, PE, and brew ratio in black drip brew coffee. Future research should now turn to other types of coffees, such as espresso and cold brew, and develop the equivalent set of BCCs for those.

5 | CONCLUSION

Our new Sensory and Consumer Brewing Control Chart displays key coffee sensory attributes in the areas of the chart where they are most fully expressed as a function of TDS and PE, as well as the liking response surfaces of the two preference segments we identified in our consumer research. Users of the classic BCC will now be able to manipulate the TDS and PE of a drip brew to achieve a specific flavor profile, as documented by the 13 attributes on the full chart, or the six attributes on the streamlined version, and to tailor to the preferences of one or the other type of consumer identified in this research, or any other that may be uncovered in future consumer studies.

AUTHOR CONTRIBUTIONS

Jean-Xavier Guinard: Conceptualization; Investigation; Funding acquisition; Writing – original draft; Methodology; Validation; Visualization; Writing – review & editing; Formal analysis; Project administration; Data curation; Supervision. **Scott Frost**: Investigation; Methodology; Writing – review & editing; Formal analysis; Data curation. **Mackenzie Batali**: Investigation; Methodology; Writing – review & editing; Formal analysis; Data curation. **Andrew Cotter**: Investigation; Methodology; Formal analysis; Data curation. **Lik X. Lim**: Investigation; Writing – review & editing. **William D. Ristenpart**: Conceptualization; Investigation; Funding acquisition; Methodology; Writing – review & editing; Formal analysis; Project administration; Supervision; Resources; Data curation.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to declare.

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