

Optimization of cold brew coffee extraction variables through sensory evaluation by Q-graders

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ABSTRACT

Cold brew is a type of coffee beverage that has recently become popular worldwide, with a future global market for 2027 worth more than a billion dollars and there is no consensus among baristas, on the internet, or in scientific literature on how to prepare this type of brew. The ranges of extraction variables such as extraction time (t), water temperature (T) and coffee-to-water ratio (R) in published works reveal end products that are quite different from each other. The purposes of this study were to develop a protocol for the quality evaluation of cold brew coffee and sensory investigate different extraction conditions of the beverage. Twenty-two cold brew beverages were produced under different levels of (t), (T) and (R) and were evaluated by coffee experts (Q-graders) in terms of eleven sensory attributes through quality scales. After statistical analysis of sensory results, desirability functions were used to perform data optimization of the flavor, balance and acidity attributes in terms of (t), (T) and (R). A novel protocol for the quality evaluation of cold brew coffee was proposed and extraction conditions leading to beverages of presumably superior quality were recommended with a coffee-to-water ratio $R=1:5$ (w/v) and 22:43 h of infusion when brewed under refrigerated temperature ($\sim 5^\circ\text{C}$) or 18:53 h of infusion under room temperature ($\sim 20^\circ\text{C}$) water. Extraction conditions leading to supposedly inferior, or average-quality beverages were also proposed.

Key words: Coffee quality; cupping; desirability; Arabica coffee; central composite design.

1 INTRODUCTION

Cold brew is a coffee beverage traditionally brewed only with roasted and ground coffee beans in cold or room temperature water, in place of traditional hot water. Since extraction efficiency is lower, it needs greater amounts of time to effectively take place, usually from 8 to 24 hours (Angeloni et al., 2018). Once the hours established for cold brew extraction have passed, the extract must be filtered before it can be consumed. Although not mandatory, the filtered drink almost always is chilled before consumption.

Cold brew coffee has become a trendy beverage in the last years among coffee lovers and can be found in coffee shops worldwide. The global market for this coffee beverage has been growing significantly. In 2017, its value was around US\$ 318 million. Since then, it has seen annual growth of more than 25% and prospects indicate that it could increase by more than US\$ 2.1 billion by 2027 (Technavio, 2022). Cold brew coffee, as a growing niche in the coffee market and with the ease of selling ready-to-drink products, may represent a possibility for coffee-growing countries to aggregate value in its chain and reduce the disadvantage in trade balance (Branco, 2015).

Superior quality products are needed to improve commercial chances, though, and the coffee industry has a long tradition of quality assessment. Green coffee beans may have a good visual appearance and still present a series of non-apparent defects that were acquired throughout the production

chain, thus needing to be tasted so that their quality can be evaluated (Lingle & Menon, 2017). This quality assessment is essentially performed by expert professionals who undergo extensive and rigorous training and are known as Q-graders or R-graders - who evaluate Arabica and Robusta coffee quality, respectively (Revi, 2019). The sensory evaluation of coffee, as performed by experts, is known as cupping and has a detailed protocol (Lingle & Menon, 2017; Revi, 2019). Cupping has been increasingly accepted within sensory sciences and an experiment with a minimum number of 6 evaluators can be considered sufficient to be scientifically valid (Louzada et al, 2018). In short, cupping is an in-depth sensory analysis of the quality of a very complex product, in which the evaluator acts as a representative of consumers (Revi, 2019).

As numerous variables can influence the outcome of a coffee beverage, one of the fundamental principles of cupping is to isolate and focus solely on one variable: the quality of the beans (Revi, 2019). This way, the brewing method, grind size, extraction time and coffee-to-water ratio, among other factors, are all standardized in a way that beverages are not under- or over-extracted. Due to the solubility of various coffee constituents, underextracted beverages are often rated as too sweet and acidic, while overextracted beverages are considered bitter and astringent, both of which are perceived as unpleasant (Mestdagh et al, 2017).

This standardization was developed by the Specialty Coffee Association of America (SCAA), which provides a series of recommendations to produce superior quality hot

brew coffee, known as the Golden Cup standard (Specialty Coffee Association of America - SCAA, 2015). It establishes optimal levels or ranges of extraction parameters (variables), namely: coffee-to-water ratio (R), water temperature (T), and time of coffee-to-water contact (t).

No similar standards for extracting cold brew coffee have ever been scientifically investigated, to the best of our knowledge. Nor has any kind of professional evaluation protocol for cold brew coffee beverages been developed until now. Cold brew coffee literature places a series of beverages extracted under very different conditions being subjected to different types of sensory and instrumental analysis. Thus, elucidating the effects of individual extraction (and any other) variables on the properties of the final cold brew coffee beverage can be a misleading task. Table 1 shows the extraction variables coffee-to-water ratio, water temperature, and extraction time with their respective levels found in various references in the cold brew coffee literature.

Cold brew coffee quality surely can be influenced by other common variables in coffee literature such as beans' origin, roasting degree, grind size, water characteristics, and so forth. Regarding water characteristics, there are guidelines and standards for its optimal quality for coffee brewing (SCAA, 2009; Colonna-Dashwood & Hendon, 2015; Wellinger et al., 2017). In prolonged solid-liquid extractions, as in cold brew coffee, the particle size of the ground beans must be coarser (Mestdagh et al., 2017). This helps prevent excessive extraction of sensory unwanted compounds to the beverage, especially those with a bitter taste (Lingle & Menon, 2017). It is possible to notice in cold brew coffee literature, as well as through recommendations from baristas, the grind size standardized at the coarse level (Angeloni et al., 2018; Kang et al., 2019; Córdoba et al., 2019, 2021a) and the roasting degree in medium level (Córdoba et al., 2019; Dwiranti et al., 2019; Heo et al., 2019, 2020; Kang et al., 2019; Bellumori et al., 2021).

Choosing an appropriate experimental design is key when investigating the existence of possible best conditions

for some response variables. The Central Composite Design (CCD) is frequently adopted for the statistical optimization of processes. When the axial point $\alpha = (2^k)^{1/4}$ is chosen, being k the number of variables, the design is called central composite rotational design (CCRD) and it is the most adopted α for optimization (Almeida et al., 2025). This experimental design allows the analysis of linear and quadratic effects, interactions between variables and accepts the construction of second-order models (Almeida et al., 2025). It has been used for the optimization of caffeine and soluble solids extraction in cold brew coffee (Barroso et al., 2022), for coffee roasting conditions (Malaquias et al., 2018), microencapsulations of green coffee extracts (Faria et al., 2020), coffee-gelatin shot formulations (Vinan et al., 2023), among other applications.

Another statistical tool to optimize conditions in multiple response situations is desirability functions. They are a set of functions proposed by Derringer and Suich (1980) used to solve simultaneous optimization problems by determining which levels of the response variables generate a better combination together (Da Silva, Kupski, & Badiale-Furlong, 2019; Almeida et al., 2025). It begins by modeling the responses of each variable into individual functions and, in sequence, generating a global function called total desirability (D). The D function is described in terms of the individual functions and replaces them, being the one that must be optimized in the end (Derringer & Suich, 1980; Da Silva, Kupski, Badiale-Furlong, 2019). Individual functions must satisfy one of three possible constraints, also known as 'desires', and can be chosen from: higher values are better; lower values are better; or a chosen nominal value between a certain maximum and a certain minimum is better (Derringer & Suich, 1980; Da Silva, Kupski, & Badiale-Furlong, 2019). This approach has been previously adopted for extractions of bioactive compounds from green beans and spent coffee grounds (Severini et al., 2017; Gigliobianco et al., 2020; Novaes et al., 2020), optimization of torrefaction conditions (Buratti et al., 2018) and formulation of an alcoholic-coffee dessert (Vinan et al., 2023).

Table 1: Levels of main extraction variables found in cold brew literature.

Coffee-to-water ratio (R) (w/v or g/mL)	Water temperature (T, °C)	Extraction time (t, h)	Reference
1:6.7	Room	24	Ahmed et al. (2019)
1:10	21-25	0-25	Fuller and Rao (2017);(Rao & Fuller, 2018)
1:11.7	20	14 and 22	Córdoba et al. (2019)
1:14.3	4	9	Heo et al. (2019)
1:20	5 and 20	12	Kang et al. (2019)
1:30	4	12	Xu et al. (2019)
1:50	n.i	n.i	Gostner et al. (2015)

n.i: not informed.

Therefore, this study aimed to propose a sensory evaluation protocol based on traditional cupping protocol and investigate optimal levels of extraction variables to produce superior-quality cold brew coffee beverages.

2 MATERIAL AND METHODS

2.1 Coffee beans

Arabica coffee beans (*Coffea arabica* L., Yellow Bourbon variety) of special quality were supplied by Coffee & Joy (Belo Horizonte, MG). They were grown at Santa Alina farm (21° 45' 40.654" S, 46° 40' 27.382" W) in São Sebastião da Grama, SP (Alta Mogiana Paulista coffee region), at an altitude of 1400 m, then hand-harvested at the cherry ripening stage with separation of defective grains and processed using the washed method (Coffee & Joy Cafés, 2022). They were roasted for about 10 min until medium degree in a Caloratto S10 2020 automatic roaster (Carmomaq, Espírito Santo do Pinhal, SP). The beans were then ground in a mill (J Mill, Varginha, MG) to coarse size ($0.85 < 76\%$ particles < 2.0 mm) and stored in airtight coffee packages with aluminum foil until use.

2.2 Water

Water was chosen among available commercial brands to be the closest possible to literature recommendations (SCAA, 2009; Colonna-Dashwood & Hendon, 2015; Wellinger et al., 2017). The 'Pouso Alto Estilo' (Pouso Alto, MG) mineral water was chosen and bought in local supermarkets. According to information from the manufacturer, pH 6.65 (at 25 °C), total solids content = 65.06 mg/L; bicarbonate = 43.63 mg/L; calcium = 6.94 mg/L; magnesium = 3.70 mg/L; sulfate = 2.14 mg/L; sodium = 1.96 mg/L; potassium = 1.38 mg/L and chloride = 0.13 mg/L. It was used for brewing all beverages in this work.

2.3 Preparation of cold brew coffee beverages

Cold brew beverages were prepared by directly infusing the roasted beans in water as usual. Initially, the designated mass of roasted and ground coffee beans was weighed on an analytical balance (model AUY220, Shimadzu) and the appropriate volume of water was obtained using a graduated cylinder. The weighted beans were placed in a dry and clean glass container in which water was added. The container was closed hermetically and stored in the absence of light in the refrigerator or at room temperature, according to the orientation of the extraction in the experimental design. All cold brew extractions were performed without shaking. After the established extraction time had elapsed, the contents of the infusion (roasted and ground coffee with water) were transferred to a support

containing a Melitta #4 paper filter (Avaré, SP), previously leached with the same water used in the preparation. Another glass container, clean and dry, was previously placed under the support with the filter to collect the filtration extract. After completing the solids separation through filtration, the resulting extract (cold brew beverages) was collected and transferred to another glass container, clean, dry, and previously identified with the code for that sample. The container with the beverages was then immediately covered and taken to refrigeration, where it remained chilled until use.

2.4 Experimental design

A Central Composite Rotational Design (CCRD) was adopted to sensory investigate the best conditions for preparing cold brew coffee beverages. The extraction variables time (t) and coffee-to-water ratio (R) were chosen as independent variables ($k = 2$). Therefore, it had a factorial portion with $2^2 = 4$ points, $2 \times 2 = 4$ axial points, in addition to 3 central points, totaling 11 experiments (Table 2). For $k = 2$, the axial point $\alpha = (2^2)^{1/4} = \sqrt[4]{2} = 1.41$.

Table 2: Central composite rotational design (CCRD) matrix with the coded values of the variables coffee-to-water ratio (R) and extraction time (t).

Experiments	R	t
1	-1	-1
2	1	-1
3	-1	1
4	1	1
5	-1.41	0
6	1.41	0
7	0	-1.41
8	0	1.41
9 (CP)	0	0
10 (CP)	0	0
11 (CP)	0	0

CP: central point.

Levels were chosen so that the extreme points of the design (-1.41 and 1.41) coincided with the extreme levels found in cold brew literature for the variables R and t , therefore (1:5 and 1:30 w/v) for the variable R and (8 and 24 h) for the variable t . To emulate the lack of precise temperature control in coffee shops or among home consumers, the variable temperature was not allocated within the CCR design. Instead, two different CCR designs were performed to evaluate a possible temperature effect. In the first design, called CCRD1, the brews were extracted under a refrigerated temperature ($T = 4\text{--}6$ °C, average of 5 °C). In a second design, CCRD2, the

brews were extracted at room temperature ($T = 18\text{--}22\text{ }^{\circ}\text{C}$, average around $20\text{ }^{\circ}\text{C}$). Table 3 shows the real levels of the variables R and t .

Table 3: Variables and their levels of CCR designs.

Variables	Levels				
	-1.41	-1	0	1	1.41
Ratio between mass of roasted and ground coffee beans and water (R , g:mL)	1:5	1:8.7	1:17.5	1:26.3	1:30
Extraction time (t , h)	8	10.3	16	21.7	24

Thus, considering both CCR designs, twenty-two cold brew beverages were produced under different conditions to be sensory evaluated.

2.5 Sensory evaluation and statistical optimization of extraction variables

Eleven sensory attributes were established to be evaluated by a score from 0 to 10 on a quality scale against Q-graders' standards for cold brew beverages. The attributes were: aroma (humid); visual (appearance); flavor; aftertaste; acidity; body; bitterness; sweetness; balance; rancidity (defect); and overall. The complete form is available in Figure S1 (Supplementary material).

Seven ($n=7$) expert evaluators took part in the study, being 4 female and 3 male all with $30 < \text{age} < 50$ and having at least 10 years of experience in the coffee industry. For all extractions, a volume of 150 mL of water was established, with the mass of coffee beans varying according to the coffee-to-water ratio of the sample. After the evaluations, the experts transcribed the results into digital forms.

As will be discussed, six attributes were found that generated valid models in both CCR designs, namely: acidity; bitterness; body; balance; aftertaste and flavor. A consultation was then carried out with the Q-graders to find out which sensory attributes, among the six with valid models, were the three most important for the quality of cold brew coffee beverages. They were asked to rank the six attributes in order of sensory importance for the brews. A criterion was established to give 6 points for the attribute considered most important, 5 points for the second most important, and so on until reaching 1 point for the attribute that was least sensory relevant to the quality of cold brew beverages.

This way, the models generated by both CCR designs for the three most relevant sensory attributes (flavor, balance, and acidity) were subjected to desirability algorithms, generating the following individual desirability functions (or 'desires'):

'Desire' 1: Highest possible scores of flavor, balance, and acidity.

'Desire' 2: Lowest possible scores of flavor, balance, and acidity.

'Desire' 3: Average scores of flavor, balance, and acidity.

The 'desires' were applied to both the CCRD1 and CCRD2 results, from beverages extracted under refrigerated and room temperature respectively.

Regarding the effect of extraction temperature, it would not be possible to directly evaluate it through the CCR designs performed, as it was only set at two levels: refrigerated ($\sim 5\text{ }^{\circ}\text{C}$) and room temperature ($\sim 20\text{ }^{\circ}\text{C}$). For this, we performed a two-level full factorial design, with level (-1) being extractions under refrigerated temperature and level (+1) being extractions under room temperature water. The design was then fulfilled with the variables R and t ($k = 3$ variables) at the same coded points (-1; +1) and the sensory evaluation results of the cold brew coffee beverages that had been extracted under the same conditions were associated with the respective points of the design. This way, it was possible to evaluate the effects of each sensory attribute. Table 4 shows the variables and the real values of the full factorial design levels.

Table 4: Variables and their levels of full factorial design.

Variables	Levels	
	-1	1
Ratio between mass of roasted and ground coffee beans and water (R , g:mL)	1:8.7	1:26.3
Extraction time (t , h)	10.3	21.7
Extraction temperature (T , $^{\circ}\text{C}$)	5	20

2.6 Data Analysis

Data were analyzed and processed with Microsoft Excel® 2016 and Statistica® 12 software. Analyses of variance (ANOVA) were performed with 95% significance ($\alpha=0.05$) in all generated models.

3 RESULTS

3.1 Sensory evaluation

The results of the average ratings for each sensory attribute performed by the experts are found in Tables S1 and S2 (Supplementary material). The p-value results of the ANOVA of the models generated for each attribute are in Tables S3 and S4.

The sensory attributes were ranked in descending order of importance, from most important to least important, and their scores, as determined by the experts, are shown in Table 5.

Table 5: Numerical assessment of the importance of sensory attributes for cold brew coffee beverages.

Attribute	Scoring sum
Flavor	22
Balance	21
Acidity	14
Aftertaste	10
Body	9
Bitterness	8

3.2 Extraction optimization

The valid models and their coefficients generated for the three most important sensory attributes for cold brew

coffee beverages (flavor, balance and acidity) in each CCR design are shown in Tables S5 and S6.

The new extraction conditions proposed by desirability functions are shown in Table 6.

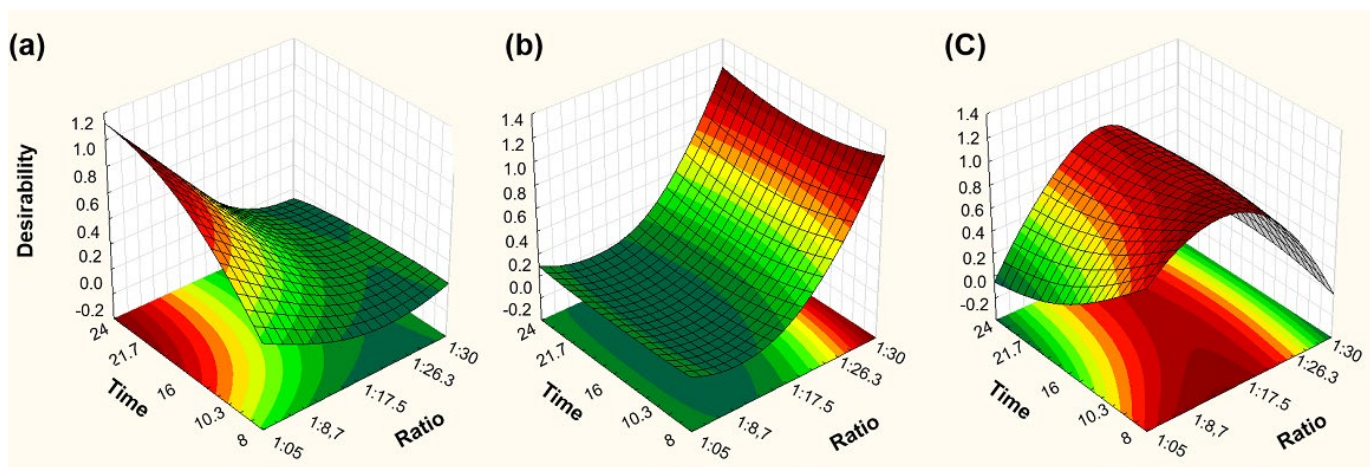
Response surfaces show how the values of the desirability function behave depending on the levels of R and t for the three ‘desires’ of CCRD1 (Figure 1).

The profiles for predicted values generated by the desirability functions indicate the optimal values for each of the three sensory attributes and are illustrated for CCRD2 in Figure 2. Figure 2a shows profiles for ‘desire’ 1 (highest scores of flavor, balance and acidity). Analogously, Figure 2b shows profiles for ‘desire’ 2 (lowest scores) and Figure 2c shows profiles for ‘desire’ 3 (average scores).

Table 6: Coded and non-coded levels of the variables coffee-to-water ratio (R) and extraction time (t) after statistical optimization of the results in CCRD 1 (refrigerated extraction) and CCRD2 (room temperature extraction).

CCRD 1 (refrigerated extraction ~ 5°C)					
‘Desire’	Coded		Non-coded		% ‘desire’ achieved
	R	t	R (w/v)	t (h:min)	
(1) Highest flavor, balance and acidity scores	-1.41	1.1844	1:5	22:43	96.743
(2) Lowest flavor, balance and acidity scores	1.41	1.41	1:30	24	100.000
(3) Average flavor, balance and acidity scores	0.282	1.2972	1:20	23:22	95.199
CCRD 2 (room temperature extraction ~ 20°C)					
‘Desire’	Coded		Non-coded		% ‘desire’ achieved
	R	t	R (w/v)	t (h:min)	
(1) Highest flavor, balance and acidity scores	-1.41	0.5076	1:5	18:53	87.827
(2) Lowest flavor, balance and acidity scores	1.41	-0.7332	1:30	11:50	100.000
(3) Average flavor, balance and acidity scores	-0.282	-0.9588	1:15	10:34	95.957

R: coffee-to-water Ratio; t: extraction time;

**Figure 1:** Response surfaces of the variables R and t obtained through desirability for the three ‘desires’ in CCRD1: (a) highest scores of flavor, balance and acidity, (b) lowest scores and (c) average scores.

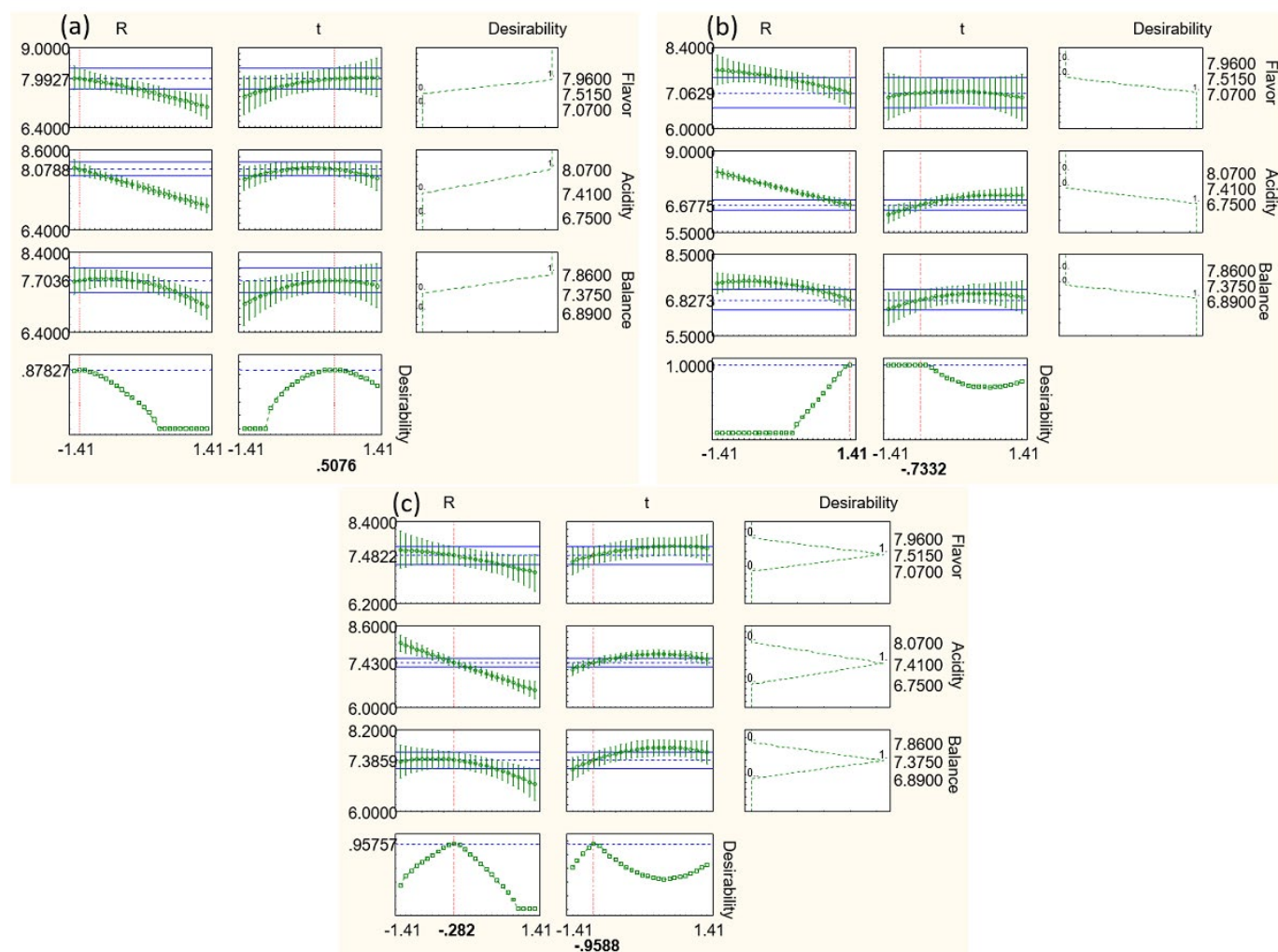


Figure 2: Profiles for predicted values of R and t by desirability functions for the three 'desires' in CCRD2: (a) highest scores of flavor, balance and acidity, (b) lowest scores and (c) average scores. The dashed red line indicates the point within the range (-1.41; +1.41) where the 'desire' is closest to being achieved.

3.3 Analysis of the effect of extraction temperature

The effects of extraction temperature and its coefficients on those two sensory attributes are shown in Table S7.

4 DISCUSSION

Analyses of variance (ANOVA) of the models generated by both CCR designs showed that, of all eleven attributes, only six (acidity; bitterness; body; balance; aftertaste; and flavor) had significant regression p-values and non-significant lack of fit (Tables S3 and S4). The difference in ratings between panelists may be related to this since this variability was higher than what normally occurs in cuppings, where total scores rarely differ by more than two units between evaluations of different experts. The higher variability among cold brew coffee sensory evaluation when compared to standard-brew

coffee beverages has been reported before and was associated with a higher degree of unfamiliarity with the former beverage (Hamilton & Lahne, 2020). Córdoba et al. (2021b) observed that sensory differences between coffee beverages produced with higher quality beans were less perceived in cold brew beverages than in hot brew beverages.

The variability was notably high among assessments of the rancidity attribute (Table S1 and S2). The Q-graders suggested this attribute to evaluate an undesirable but common characteristic in cold brew coffee beverages. It was included as an attribute that could reduce the total score of beverages, just as the bean's 'defects' attribute does in the original SCA protocol. Therefore, this score was inverted, that is, the worse the perceived rancidity, the more points the sample would lose, limited to -10 in the case of an unbearably rancid beverage. However, unlike traditional cupping where the quality of coffee beans is evaluated, there are no standardized criteria among coffee associations to evaluate the quality of

cold brew beverages. Therefore, the judgment of the quality of attributes for cold brew coffee beverages was carried out based on the personal experience of each evaluator with this type of beverage. Although they all have vast experience with coffee beverages, prior training of panelists specifically for a new sensory evaluation protocol and the standardization of specific quality standards for cold brew coffee beverages seem necessary to standardize the criteria and minimize variations.

To achieve statistical-sensory optimization through quality scales, individual desirability functions ('desires') were established according to the scores of the three most important sensory attributes (flavor, balance and acidity), among those six that generated valid models. For better sensory discrimination and instrumental studies to be performed in future work, they needed to be as different as possible from each other, as it could improve the evaluation of extraction variables' effects. Therefore, we sought the levels of extraction variables that could be associated with the best possible quality beverages ('desire' 1), the worst possible quality ('desire' 2), and beverages of average quality ('desire' 3).

In 'desire' 1, the highest values of the desirability function were grouped in the region of more concentrated beverages and longer extraction times (Figure 1a). In 'desire' 2, the optimum region occurred in the most diluted beverages, with little variation between time levels (Figure 1b). In 'desire' 3, analogous behavior occurred with time, but the desirability function was maximized in regions of intermediate coffee-to-water concentrations (Figure 1c).

In the full factorial design, the temperature had a significant effect only for flavor and bitterness, among the eleven sensory attributes evaluated (Table S7). Even considering $\alpha=0.1$, no significant effect occurred in any other attribute. For the flavor attribute, only the interaction effect of temperature with the coffee-to-water ratio (R) was significant and positive. Regarding the bitterness attribute, temperature had a significant positive linear effect, as was significant also its negative interaction with time. Thus, the potential effect of extraction temperature on the evaluated sensory attributes proved to be quite small. Angeloni et al. (2019) reported that the temperature had a significant effect on the sour taste of cold brews, being a beverage extracted under 22 °C having a higher sour intensity than the one extract under 5 °C.

Portela et al. (2022) found no differences in preference among coffee consumers when analyzing cold brew beverages extracted under specific conditions. Hamilton and Lahne (2020) concluded that roast level was the variable that most influenced cold brew flavor. Cordoba et al. (2019) reported no significant differences among the scores of six different sensory attributes (aroma, taste, aftertaste, acidity, body, overall impact) when studying cold brew coffee brewed under two distinct extraction times (14 h and 22 h), even with beans

from different origins. Maksimowski et al. (2022), on the other hand, reported differences among flavour compounds in cold brew coffee brewed under different extraction times and temperatures. Angeloni et al. (2019) findings corroborate these same results and report that the type of method (cold brew vs cold drip) is also associated with differences in sensory profile. Another study has also concluded that sensory analysis methods for cold brew coffee led to distinct flavors, flavor intensities, consumer liking scores and drivers of liking (McCain-Keefer, Meals & Drake, 2020).

Further studies will be conducted investigating how differences in the sensory profiles of cold brew coffee brewed under steep different conditions of (t), (T) and (R) simultaneously are perceived and which physicochemical properties these optimal or sub-optimal extraction levels can be related. The former can contribute to the applicability and development of sensometrics methods for similar beverages; the latter can shed light on what makes a good or bad cup of cold coffee beverage and improve standards in the coffee industry.

5 CONCLUSIONS

This research developed a new quality-based evaluation protocol for cold brew coffee, establishing that superior beverages maximizing flavor and acidity result from a 1:5 coffee-to-water ratio extracted for approximately 23 hours (refrigerated) or 19 hours (room temperature). Conversely, a 1:30 ratio yields inferior quality. These optimized parameters provide a standardized framework for the coffee industry and a foundation for future sensory and physicochemical studies

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7 AUTHOR CONTRIBUTION

Conceptual Idea: Miceli, C. F.; Novaes, F. J. M.; Rezende, C. M.; Methodology design: Miceli, C. F.; Novaes,

F. J. M.; Melo, L.; Data collection: Miceli, C. F.; Data analysis and interpretation: Miceli, C. F.; Melo, L.; and Writing and editing: Miceli, C. F.; Novaes, F. J. M.; Melo, L.; Rezende, C. M.

8 REFERENCES

- Ahmed, M. et al. (2019). Effects of ultrasonication, agitation and stirring extraction techniques on the physicochemical properties, health-promoting phytochemicals and structure of cold-brewed coffee. *Journal of the Science of Food and Agriculture*, 99(1):290-301.
- Almeida, E. R. V. et al. (2025). A review of the use of central composite design in the optimization of procedures aiming at food chemical analysis. *Food Chemistry*, 480:143849.
- Angeloni, G. et al. (2018). Characterization and comparison of cold brew and cold drip coffee extraction methods. *Journal of the Science of Food and Agriculture*, 99(1):391-399.
- Barroso, L. A. et al. (2022). Optimization of the brewing parameters on coffee extraction using a central composite rotatable design. *JSFA reports*, 2(3):107-115.
- Bellumori, M. et al. (2021). Effects of different stabilization techniques on the shelf life of cold brew coffee: Chemical composition, flavor profile and microbiological analysis. *LWT*, 142:111043.
- Branco, M. (2015). Estudo indica que brasil tem dificuldade para exportar café com valor agregado. EBC, 15 aug. 2015. Available in: <<https://agenciabrasil.ebc.com.br/economia/noticia/2015-08/estudo-indica-que-brasil-tem-dificuldade-para-exportar-cafe-com-valor>>.
- Buratti, C. et al. (2018). Optimization of torrefaction conditions of coffee industry residues using desirability function approach. *Waste Management*, 73:523-534.
- Coffee & Joy Cafés. (2022). Terracota. Coffee & Joy. Available in: <<https://coffeeandjoy.com.br/coffees/52-terracota>>.
- Colonna-Dashwood, M., & Hendon, C. (2015). Water for coffee. Self-Publication. Bath, UK.
- Córdoba, N. et al. (2019). Effect of grinding, extraction time and type of coffee on the physicochemical and flavor characteristics of cold brew coffee. *Nature Scientific Reports*, 9:8440.
- Córdoba, N. et al. (2021a). Chemical and sensory evaluation of cold brew coffees using different roasting profiles and brewing methods. *Food Research International*, 141:110141.
- Córdoba, N. et al. (2021b). Specialty and regular coffee bean quality for cold and hot brewing: Evaluation of sensory profile and physicochemical characteristics. *LWT*, 145:111363.
- Da Silva, B., Kupski, L., & Badiale-Furlong, E. (2019). Central composite design-desirability function approach for optimum ultrasound-assisted extraction of daidzein and genistein from soybean and their antimycotoxigenic potential. *Food Analytical Methods*, 12(1):258-270.
- Derringer, G., & Suich, R. (1980). Simultaneous optimization of several response variables. *Journal of Quality Technology*, 12(4):214-219.
- Dwiranti, N. S. et al. (2019). Sensory attributes of cold brew coffee products at various resting time after roasting process. *Pelita Perkebunan*, 35(1):42-50.
- Faria, W. C. S. et al. (2020). Design and evaluation of microencapsulated systems containing extract of whole green coffee fruit rich in phenolic acids. *Food Hydrocolloids*, 100:105437.
- Fuller, M., & Rao, N. Z. (2017). The effect of time, roasting temperature, and grind size on caffeine and chlorogenic acid concentrations in cold brew coffee. *Nature Scientific Reports*, 7:17979.
- Gigliobianco, M. R. et al. (2020). Optimization of the extraction from spent coffee grounds using the desirability approach. *Antioxidants*, 9(5):370.
- Gostner, J. M. et al. (2015). Coffee extracts suppress tryptophan breakdown in mitogen-stimulated peripheral blood mononuclear cells. *Journal of the American College of Nutrition*, 34(3):212-223.
- Hamilton, L. M., & Lahne, J. (2020). Assessment of instructions on panelist cognitive framework and free sorting task results: A case study of cold brew coffee. *Food Quality and Preference*, 83:103889.
- Heo, J. et al. (2019). Cold Brew coffee: Consumer acceptability and characterization using the check-all-that-apply (CATA) Method. *Foods*, 8(8):344.
- Heo, J. et al. (2020). Analysis of caffeine, chlorogenic acid, trigonelline, and volatile compounds in cold brew coffee using high-performance liquid chromatography and solid-phase microextraction-gas chromatography-mass spectrometry. *Foods*, 9(12):1746.

- Kang, D. et al. (2019). Comparison of acrylamide and furan concentrations, antioxidant activities, and volatile profiles in cold or hot brew coffees. *Food Science and Biotechnology*, 29(1):141-148.
- Lingle, T. R., & Menon, S. N. (2017). Cupping and grading-discovering character and quality. In B. Folmer (Ed.). *The craft and science of coffee*. Academic Press. (pp.181-203).
- Louzada, L. P. et al. (2018). Propositions on the optimal number of Q-Graders and R-Graders. *Journal of Food Quality*, Article ID 3285452.
- Maksimowski, D. et al. (2022). Coffee roasting and extraction as a factor in cold brew coffee quality. *Applied Sciences*, 12(5):2582.
- Malaquias, J. V. et al. (2018). Optimization of the roasting conditions of arabica coffee cultivated in the cerrado area of Brazil. *Brazilian Journal of Food Technology*, 21:e2016162.
- Mccain-Keefer, H. R. et al. (2020). The sensory properties and consumer acceptance of cold brew coffee. *Journal of Sensory Studies*, 35(6):e12604.
- Mestdagh, F. et al. (2017). The brew. Extracting for excellence. In B. Folmer (Ed.). *The craft and science of coffee*. Academic Press. (pp. 355-380).
- Novaes, F. J. M. et al. (2020). Isolating valuable coffee diterpenes by using an inexpensive procedure. *Industrial crops and products*, 152:112494.
- Portela, C. et al. (2022). Effects of brewing conditions and coffee species on the physicochemical characteristics, preference and dynamics of sensory attributes perception in cold brews. *Food Research International*, 151:110860.
- Rao, N. Z., & Fuller, M. (2018). Acidity and antioxidant activity of cold brew coffee. *Nature Scientific Reports*, 8:16030.
- Revi, I. (2019). Coffee cupping: evaluation of green coffee quality. In A. Farah. *Coffee: Production, quality and chemistry*. Royal Society of Chemistry, Croydon, United Kingdom. (pp.335-360).
- Specialty Coffee Association of America - SCAA. (2009). Water for brewing specialty coffee. Available in: < https://web.archive.org/web/20230721130916id_/http://www.scaa.org/PDF/resources/water-standards.pdf >.
- Specialty Coffee Association of America - SCAA. (2015). Golden Cup Standard. Available in: < https://web.archive.org/web/20230510044145id_/https://www.scaa.org/PDF/resources/golden-cup-standard.pdf >
- Severini, C. et al. (2017). Ultrasound-assisted extraction to improve the recovery of phenols and antioxidants from spent espresso coffee ground: a study by response surface methodology and desirability approach. *European Food Research and Technology*, 243:835-847.
- Technavio. (2022). Cold Brew coffee market by product, distribution channel, and geography - forecast and analysis 2023-2027. [online] Technavio, nov. 2022. Available in: <<https://www.technavio.com/report/cold-brew-coffee-market-industry-analysis>>.
- Vinan, P. A. S. et al. (2023). Optimization of coffee-gelatin shot formulations based on physicochemical, rheological and sensory properties using response surface methodology. *Journal of Food Industry*, 7(1): 54-72.
- Wellinger, M. et al. (2017). Chapter 16. Water for extraction - composition, recommendations, and treatment. In B. Falmer. *The craft and science of coffee*. Elsevier Academic Press, Cambridge, EUA. (pp.381-398).
- Xu, L. et al. (2019). Use of liquid chromatography quadrupole time-of-flight mass spectrometry and metabolomic approach to discriminate coffee brewed by different methods. *Food Chemistry*, 286:106-112.