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A design of experiment strategy for quality control of specialty coffee drink based on sensory analysis and statistical tools

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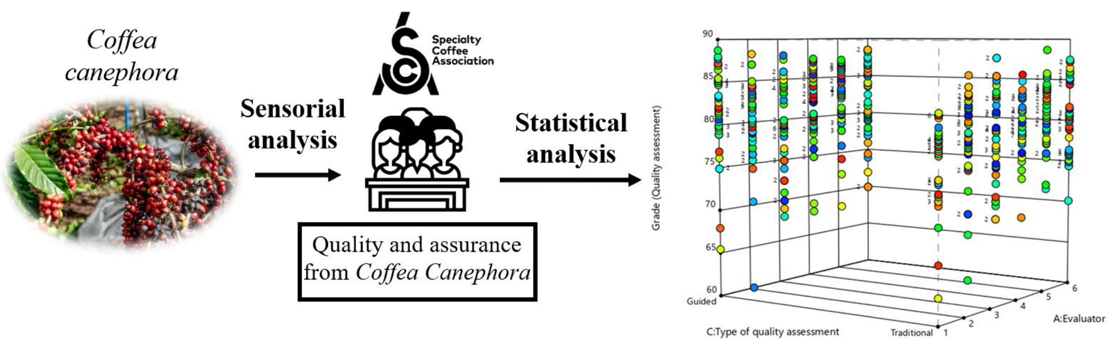
Abstract

Sensory analysis is crucial for assessing food and beverage quality, but discrepancies may arise in some cases and make the quality evaluation imprecise even with statistical analysis. This issue can be mitigated by sensory analysis based on the coffee drink nuanced characteristics. Therefore, in this study, six Q-Graders, following the Specialty Coffee Association of America's sensory analysis method, evaluated various samples and the data was evaluated statistically. The experiment employed a multilevel categorical design, encompassing six evaluator levels, 44 sample levels, and two types of quality assessment. Grades were assigned to the 44 samples using traditional evaluation (no comments) and guided evaluation (prior sample information). It was possible to identify evaluators whose assessments were unbiased across both guided and traditional evaluations. This work introduced a novel strategy to identify biased evaluators, assess the impact of evaluation types, and perform a more accurate assessment of *Coffea canephora* Pierre ex-Froehner (coffee) quality and assurance assisted with statistical analysis.

Keywords: *Coffea canephora*; Sensory analysis; Coffee; Chemometrics; Experimental design; Quality assessment.

Graphical Abstract



Highlights

- New food control method to evaluate the coffee drink quality assessment
- Design of experiment analysis for coffee quality control
- Statistical analysis to reduce the human bias effect on the assessment of specialty coffee quality

1 Introduction

Coffee is the second most consumed beverage in the world (Empresa Brasileira de Pesquisa Agropecuária, 2023). Regarding coffee production, Brazil holds an important position as one of the main producers and exporters. Brazilian coffee reached an estimated production of 60 million bags of processed grain in 2023 (Companhia Nacional de Abastecimento, 2023a), where *Coffea arabica* L. may represent 75% of national production while *Coffea canephora* Pierre ex Froehner is approximately 25% (Companhia Nacional de Abastecimento, 2023b).

The quality assurance of the produced coffee is one important factor to be considered, where the tools used for monitoring the quality are directly related to the price and quality of the final product. The aroma and striking flavor can be used for quality assurance, presenting good estimators of the coffee quality, these parameters consist of a combination of chemical compounds directly related to the coffee origin, species, and roasting procedure. Despite the low weight of 0.1% of aromatic compounds in the total weight of roasted coffee, it is one of the most aromatic foodstuffs (Gerhard, 2006).

The feeling of well-being and pleasure with coffee consumption are related to the perception of aroma and flavor since sensory characteristics are important points for the quality and acceptance of coffee (Moreira et al., 2001). Therefore, coffee quality is often assessed through sensory analysis, a technique used to evaluate a product's sensory characteristics, such as aroma, flavor, texture, and appearance.

Coffea canephora, also known as *Robusta Coffee*, is a species of coffee plant widely cultivated in various tropical regions around the world, including Africa, Asia, and South America. It is one of the most common species of commercially grown coffee plant, it is valued for its resistance to diseases and pests, as well as for its productivity (Berthaud & Charrier, 1988). In the sensory analysis of *C. canephora* aspects such as aroma, flavor, body, acidity, and bitterness are evaluated, since it tends to have a stronger and more bitter taste compared to *C. arabica*, due to its higher caffeine content and profile with a more intense flavor (Martinez et al., 2014).

Sensory analysis is the technique used to identify small particularities and nuances of coffee (Cheng et al., 2016; Civille & Oftedal, 2012; Louzada Pereira et al., 2018; Pereira et al., 2017; Ribeiro et al., 2014; Souza et al., 2021). This technique helps in the description and classification of different aspects of coffee flavor, and it has been a very important tool in the characterization of different types of coffee and consists of a complex process based on human perception, thereby being highly subjective and dependent on trained professionals (Civille & Oftedal, 2012; Louzada Pereira et al., 2018; Pereira et al., 2017; Ribeiro et al., 2014; Spence & Carvalho, 2019). Therefore, sensory analysis presents more reliable results when performed by professionals known as Q-Graders (quality Q evaluators). These professionals are certified by the Coffee Quality Institute (CQI) and become “experts” in the field of coffee tasting, thus being able to perform an efficient sensorial analysis, through the use of taste and aroma in a rigid tasting of the specificities of the bean (Civille & Oftedal, 2012).

A sensory evaluation method that stands out in assessing the quality of specialty coffee is the Specialty Coffee Association of America (SCAA), a technique based on a descriptive quantitative sensory analysis of the beverage (Ted, 2011). Q-Graders assess coffee characteristics using punctuation scales and sensory descriptions. The results are statistically analyzed to provide information about the quality and sensory characteristics of the coffee such as color, smell, taste, and mouthfeel (Louzada Pereira et al., 2018; Pereira et al., 2017). However, the number of tasters used in the sensory analysis may compromise the quality of the study, since a smaller number of tasters can cause a loss of precision, while a larger number makes the analysis more expensive (Louzada Pereira et al., 2018; Pereira et al., 2017). Besides, even with qualified Q-Grader's evaluators, biased evaluation may be present and makes the quality assessment of coffee drinks difficult to access using the current statistical analysis tools.

Therefore, this work aimed to use two different types of quality assessment and the structure of design of experiment (DOE) statistical analysis as a new strategy to better assess the non-biased Q-Graders evaluators and to accurately assess the quality and assurance of the *C. canephora*. It should be highlighted that the experimental design model was used to evaluate the coffee grade quality and the interaction between the type of quality assessment, the samples, and the evaluators, but not to search for an optimal parameter as usually done when DOE strategy is used (Lundstedt et al., 1998a; Steven Brown et al., 2020).

2 Materials and methods

2.1 Experimental

2.1.1 Samples selection and preparation

Samples were collected from different regions in Brazil (Table 1) during the 2020 harvest (in private farmer properties and Embrapa's research center). All crops were grown in three years and managed as recommended by Marcolan (Marcolan et al., 2009). Six liters of coffee beverage were collected per clone, in the cherry stage, according to the scale of the reproductive phenological stages of coffee in Rondônia (RO) (Marcolan et al., 2009).

On the same day after collection, the fruits were washed, and selected by removing green and floating grains. The selected grains were then placed for drying in the sun over the canvas until the samples reached between 11% and 12% moisture. After drying, the coffees were kept for a maximum of 30 days, until sensory analysis. Table 1 summarizes the analyzed samples by origin, location, type of processing, and botanical variety. There were 17 samples from Embrapa's research center, 13 from Indigenous, and 14 from producer which show a relatively well-balanced sample set.

Table 1. Coffee samples of coffee trees (*Coffea canephora* Pierre ex Froehner) from different origins, locations, types of processing, and botanical varieties.

Samples	Origin	Location (Brazilian City - State)	Type of processing	Botanical variety
1 a 10	BAG Embrapa	Ouro Preto do Oeste - RO	Natural	Robust
11 a 16	BAG Embrapa	Ouro Preto do Oeste - RO	Natural	Hybrid
17	BAG Embrapa	Ouro Preto do Oeste - RO	Natural	Conilon
18 a 30	Indigenous	Alta Floresta D´Oeste - RO	Fermented	Hybrid
31 a 34	Producer	Nova Venécia - ES	Natural	Conilon
35 a 37	Producer	São Domingos do Norte - ES	Natural	Conilon
38	Producer	Caxixe Quente - ES	Natural	Conilon
39	Producer	Jeronimo Monteiro - ES	Natural	Conilon
40 a 41	Producer	Muniz Freire - ES	Natural	Conilon
41 a 43	Producer	Muqui - ES	Natural	Conilon
44	Producer	Mimoso do Sul - ES	Natural	Conilon

2.1.2 Sensory analysis

The coffee roasting process was conducted in a roaster (Pinhalense, model TC-02) for about 12 min at 190 °C ± 10 °C. The roasting was monitored by a set of Agtron-SCA discs, and the roasting point of samples was between the colors determined by discs # 65 and # 55, for specialty coffees (Specialty Coffee Association of America, 2015).

The samples were evaluated between 08 and 24 hours after roasting. Then, they were ground in a Ditting 5.5 electric mill (Ditting Maschinen AG, Bachenbulach, Switzerland) to medium/coarse grain size. Five cups of each coffee batch were tasted, using a concentration of 8.25 g of ground coffee in 150 mL water, following the midpoint of the balance chart (Specialty Coffee Association of America, 2015). The infusion points of water occurred after the water reached 92.2 ºC to 94.4 ºC. The evaluators (judges/cuppers) started evaluations when the cup temperature reached 55 ºC, respecting the time of 4 min for tasting after infusion.

In this method, only the beverage is evaluated, excluding defects; all the samples present a score of 36. Beginning at this point, the scores of each attribute (from 0 to 8) are totaled to compose the final score. The beverage quality score follows a scale from 36 to 100 points. If the coffee sample achieves a final score greater than or equal to 80 points, it is classified as a specialty coffee (Specialty Coffee Association of America, 2015). The sensory opinions of the cuppers of each sample were registered during the coffee cupping sessions as the beverage nuances of the coffee.

Sensory analysis of the samples was carried out in the laboratory of Coffee Union from October 12th to 16th of 2020 by six judges/cuppers (R Grader), according to the sensory analysis method of the Specialty Coffee Association of America (2015). In searching to quantify the efficiency of sensory evaluations and to evaluate the influence of some sample information on the evaluator's grade, which may lead to biased attributed grades, the same samples were randomly submitted to evaluation on a different day. The randomization consists of aleatory serving the samples to the Q-Graders evaluators. It was taken care to ensure that the coffees were not served in the same order as the previous day. On the first day, the samples were randomly offered without any prior information (traditional evaluation), and on the second day, the samples were randomly offered to the evaluators with some information about the sample's origin and method of preparation (guided assessment).

2.2.3 Statistical analysis

The statistical analysis strategy was carried out based on a multilevel categorical design of experiment (DOE) organization (Lundstedt et al., 1998b, 2020b), where three factors were studied, as follows: (1) the evaluator (judges), (2) the samples and (3) the type of quality assessment. The total of 528 responses consists of the grades attributed for the 44 coffee samples by the 6 judges after the process of quality assessment in a traditional and guided method that was performed on different days. This multilevel categorical design of experiment organization is shown in Table 1S in the supplementary material where the grades were presented for each one of the 528 experiments.

Using these results two models were built, the first one was used to evaluate if there is any difference between the evaluation of the judges by traditional and guided method for all samples. The evaluator's grades, which present a biased result with both types of quality assessment, were then removed before building the second model, which was used to assess the quality of each sample and the presence of systematic effect over the method of quality assessment used. All the calculations were performed with Design Expert software. With the random evaluation of the samples by the six Q-grade evaluators, the two-fold analysis (guided and traditional), and the statistical analysis, it is expected that the quality assessment of the coffee samples can be more accurately achieved using the protocol proposed with a better compromise between effectiveness and cost (Louzada Pereira et al., 2018; Pereira et al., 2017).

3 Results and discussion

The results shown in Figure 1 represent a 3d plot of the grade attributed by six Q-graders tasters for 44 coffee samples by traditional and guided type of quality assessment. All these 528 grades were organized for a multilevel categorical experimental design analysis (Table 1S), where significant differences were searched for the three factors: (1) evaluator, (2) samples, and (3) type of quality assessment and their interactions. The normal distribution of the grade's values was previously confirmed by a Shapiro-Wilk normality test and by visual inspection of the frequency distribution histogram and a normal QQ plot (data not shown). As the data follow a normal distribution the experimental design analysis can be conducted using parametric approaches based on normal distribution premises.

Even before the experimental design analysis, it is possible to observe (in Figure 1**)** differences in the grades attributed by evaluator 1 for all 44 samples, where higher grades were attributed for the samples where guided evaluations were performed. This indicates that a systematic effect may be present on evaluator 1 analysis and would prejudice the overall analysis and quality assessment of the samples. A statistical significance analysis of both types of quality assessment was confirmed using an experimental design model. This statistical analysis of evaluator 1 attributed grade after the traditional and guided evaluation was shown in Figure 1S, where the low accuracy and systematic differences on this evaluator were observed.

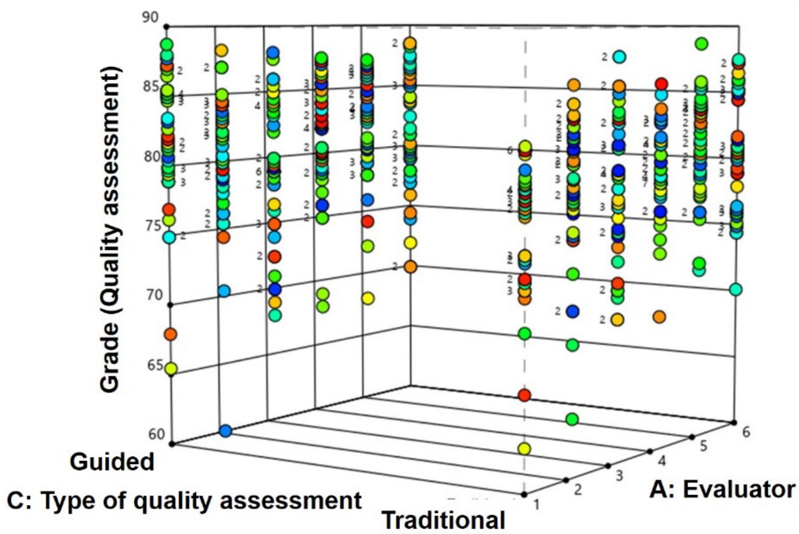


Figure 1. Grade distribution (z-axis) of 44 coffee samples by 6 Q-Grader's tasters using the traditional and guided type of quality assessment. Each filled circle represents a sample grade.

Before removing the grades from Evaluator 1, a model was built to evaluate the significance of this difference. Figure 2 shows that there is a significant difference in the grades attributed by Evaluator 1 for every sample independent of the variety and origin. The differences in grade attributed by Evaluator 1 showed that with guided evaluation this Q-Grader tastes tends to give higher grades to all coffee samples (except Embrapa Conilon and Embrapa Hybrid samples), and these differences were especially higher for (*Espírito Santo* (ES) products. There is a consistency in the grades for the other evaluators, once the differences between guided and traditional evaluation did not significantly differ. For samples obtained by the ES producers, all the evaluators tend to give higher grades, but only evaluator 1 presents a statistical difference from the attributed grade. Therefore, only the grades attributed by evaluator 1 were removed from the model used to assess the quality of the coffee samples.

After the removal of Evaluator 1 from the data, the grades of the samples were reduced from 528 to 440. The multilevel categorical experimental design, built with these 440 samples, indicates that all the main factors and two second-order interaction factors present significant effects as shown in Figure 3. The half-normal plot (Figure 3) indicates whether the factors are significant or not by the distance from the normal distribution line (red line). When factor points are distant from the red line, it indicates that its variance is significantly higher than the residues, so it presents a relevant influence on the model.

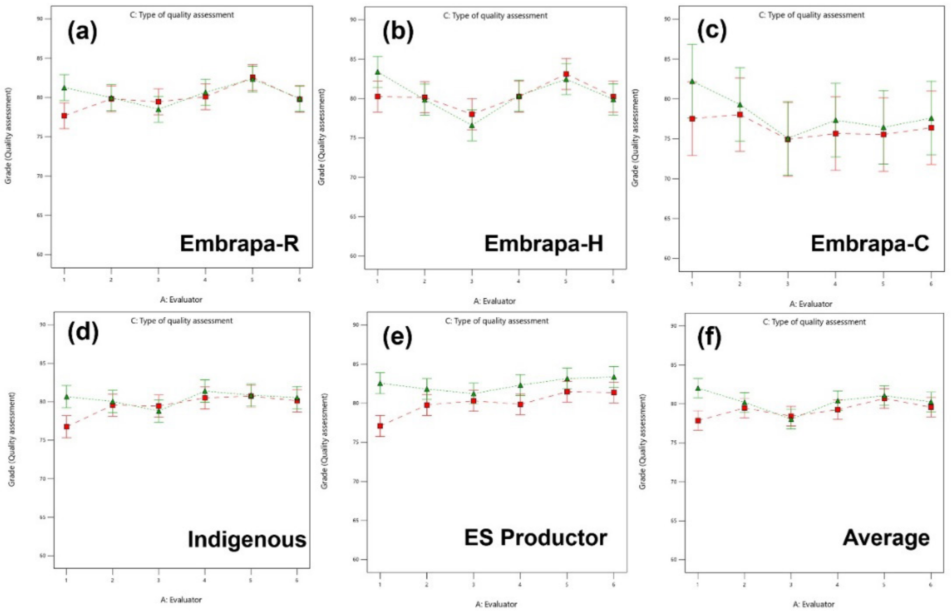


Figure 2. Grade attributed for the samples by the evaluators using traditional (red line) and guided (green line) type of quality assessment. The statistical comparison between the way the grade was calculated for each evaluator using (a) Embrapa robust, (b) Embrapa Hybrid, (c) Embrapa Conilon, (d) Indigenous, (e) productor from *Espírito Santo* and (f) the average values for each sample.

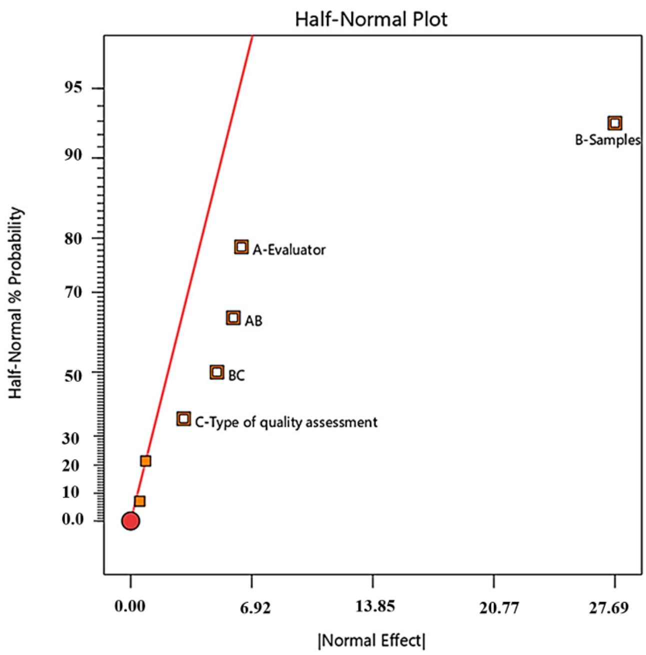


Figure 3. Half normal plot for the factors and their interactions based on the multilevel categorical experimental design. The normal distribution is indicated by the red line.

It can be seen in Figure 3 that the higher influence relies on the samples, which was expected if the results of the evaluator were consistent even with both types of quality assessment. In this case, the highest influence relies on the quality of each coffee sample, and the results of each Q-grade evaluator remain similar between them even with traditional and guided evaluation, which is important to ensure no bias in the statistical analysis. Before removing Evaluator 1, there was a significant interaction between the evaluator and the type of quality of assessment. The results shown in Figure 3 and Table 2, calculated after removing the Evaluator 1 grades, indicate that the grade depends mostly on the sample and its interaction. In addition, these results indicated that there is no dependence between the evaluator and the way the analysis was conducted, which guarantees that now the grades attributed by the evaluators are accurate and do not depend on the type and day of the evaluation. This information was only possible to be accessed due to the present DOE-based analysis strategy.

Table 2. Analysis of variance of the multilevel categorical model.

Source	SS	Df	MS	F-Value
A - Evaluator	283.69	4	70.92	12.72
B - Samples	5232.97	43	121.70	21.83
C – Type of quality assessment	51.34	1	51.34	9.21
AB	1678.40	172	9.76	1.75
BC	574.11	43	13.35	2.39
Residue	981.29	176	5.58	--
Total	8801.80	439	--	--

There is still significance for the evaluator and the type of quality assessment, which may be due to differences for some samples indicating that there are small differences in the attributed grades for some samples by the evaluators. There is a clear significance for the samples, which was already expected once the quality of the coffees analyzed differed. The small significant interaction between the type of quality assessment and samples may indicate that the grades differed for some samples when they were attributed after traditional or guided assay. The analysis of variance (ANOVA) shown in Table 2 reinforces that the highlighted factors and interactions present significantly higher variance when compared to the residue indicated by the SS value and the F test at a 5% significance level.

It is important to highlight that the explained variance of this model is 89%, which shows that the built model is efficient in explaining the variance between the Evaluator, Samples, Type of quality assessment, and their interaction with the grade attributed by the most accuracy Q-Graders tasters to the samples. The interactions of evaluators and samples (AB) and samples and type of quality assessment (BC) were respectively discoursed in Figures 4 and 5. To reinforce the quality of the model, it was performed the calculations of the normal QQ-plot for the raw data and the residue of the built DOE model for both models with and without the biased evaluator. The cumulative distribution was also calculated to prove the normal distribution of the data and it was presented in Figure 2S in the Supplementary Material. Both QQ-plot and cumulative distribution were calculated using a chemometric web app developed in R (Darzé et al., 2022).

Figure 4 shows the interaction plot between the evaluators and the samples. The grade results are the mean value of traditional and guided methods. The interaction plot gives a better evaluation of how the grades vary and if there is an influence between the analyzed factors. It is possible to see in Figure 4a that the variance between the grades attributed to the samples is similar for all evaluators, which contributes to reaffirming the accuracy of the analysis. In Figure 4b, it was shown the results of all samples attributed by each evaluator, it can be seen that the grades attributed for each sample are similar between the evaluators. A discrepancy in the grade can be seen only for the grade attributed by Evaluator 5 to sample 3 and by Evaluator 2 to sample 27, which were highlighted in red circles in Figures 4 a and b and respectively correspond to Embrapa's and Indigenous coffee as can be seen at Table 01. Besides this discrepancy, the classification as a specialty coffee for sample 3 with a grade higher than 80 and non-specialty coffee for sample 27 with a grade lower than 80 was maintained for all evaluators (Louzada Pereira et al., 2018; Pereira et al., 2017; Specialty Coffee Association of America, 2015), therefore these samples were kept to guarantee variance in the error of the built model. This difference confirms the interaction effect between samples and evaluators (see Figure 3 and

Table 2), once each evaluator may attribute different grades to some samples although the overall classification of coffee drink quality was maintained.

Figure 5 presents the interaction plot of samples and type of quality assessment for individual evaluators and the mean grades attributed to all evaluators. Consistency of the attributed grades for the samples can be seen for all samples and evaluators; including the tendency for sample 27, where the grade was significantly lower, and for sample 43 where the grades were significantly higher for all evaluators when guided evaluations were performed. These differences were highlighted in Figure 5a with red circles and indicate that there is an interaction between samples and the type of quality assessment.

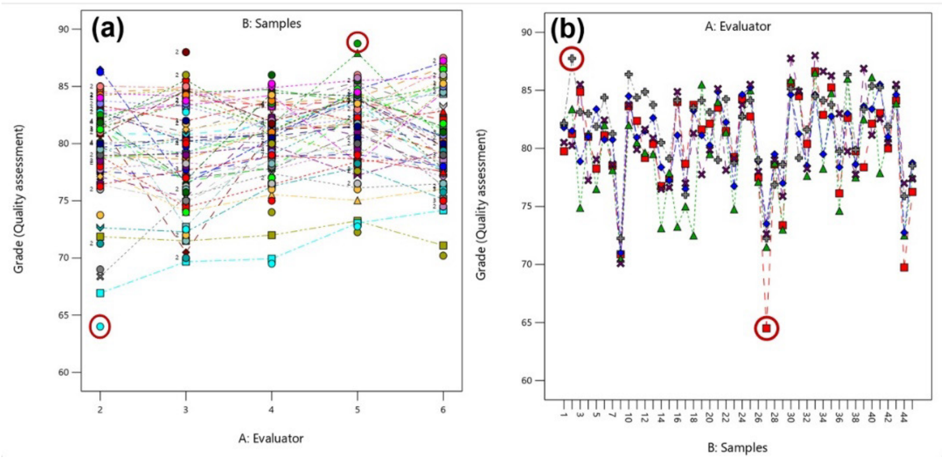


Figure 4. Interaction plot of Evaluator and Samples (AB, see Figure 3) for the samples analyzed by each evaluator (a) and for the evaluator's grade attributed for each sample (b). In (a) each line corresponds to a different sample and in (b) each line corresponds to an evaluator where red squares, green triangles, blue diamonds, gray crosses, and purple Xs respectively correspond to evaluators 2, 3, 4, 5, and 6. The circled samples present two grades that significantly differ from the mean for that sample.

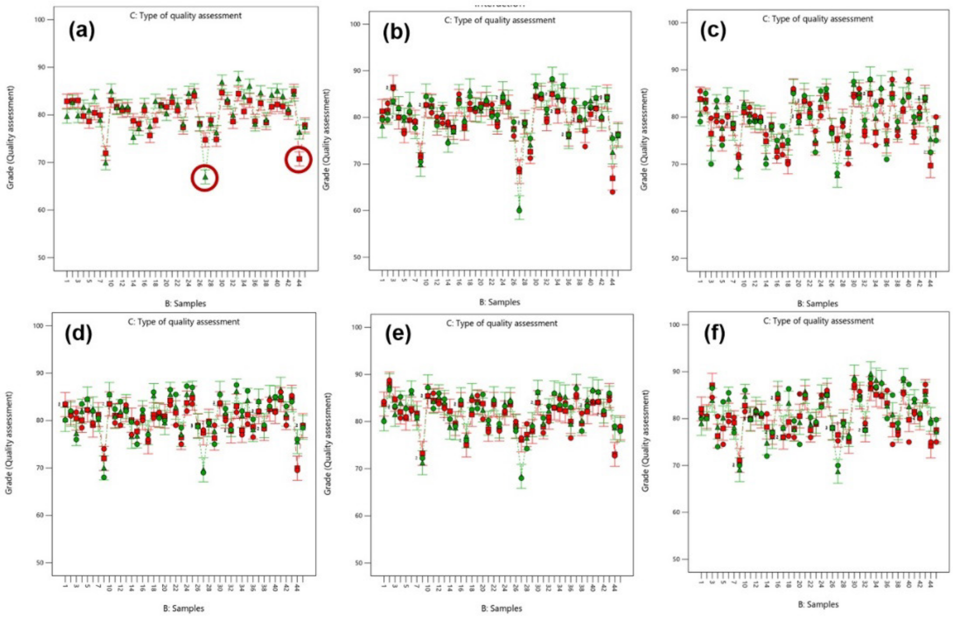


Figure 5. Interaction plot of samples and type of quality assessment (BC, see Figure 3). Green triangles and red squares values respectively represent the guided and traditional type of quality assessment. The values with error bars are shown for the mean results of all evaluators (a), evaluator 2 (b), 3 (c), 4 (d), 5 (e), and 6 (f). The red and green circles at b-f are the specific grades attributed by that respective evaluator. Samples 27 and 43 were highlighted once they statistically differed for the mean analysis of all evaluators from guided and traditional quality assessment (a).

Because of some samples, there are differences between guided and traditional evaluations. This analysis shows that the guided evaluation induces the evaluator to, significatively, underestimate the quality of one indigenous coffee sample and to overestimate the quality of one sample obtained from one *Espírito Santo* producer. Besides, a tendency to attribute a higher grade is observed for all evaluators, when it was used a guided method, for the grades attributed for the producer samples (samples 31-44), although these differences were not statistically different from the model residue. These results reinforce the advantage of the present strategy based on a two-fold type of quality assessment combined with experimental design-based statistical analysis, which seems to be an efficient and non-tendencious tool to assess the quality of coffee samples and guarantee the quality attribution for each coffee sample.

4 Practical applications

Traditional sensory evaluations are subject to variations due to human subjectivity, making quality assessment imprecise even with qualified evaluators. The practical application of this work relies upon the coffee industry's quality control process.

Biased evaluation can be identified by comparing the impact of each evaluator in different evaluation types: traditional (without) and guided (with previous sample information). For this purpose, the authors propose a novel approach involving two types of sensory quality assessment by six Q-Graders, certified coffee quality evaluators, assessed for 44 coffee samples. Statistical analysis using a multilevel categorical design of experiments (DOE) was employed to analyze the data.

This method not only benefits coffee producers by improving their product quality but also provides consumers with more consistent and reliable sensory experiences when enjoying specialty coffee. The combination of sensory analysis and statistical tools can enhance coffee quality assurance and ultimately promote the specialty coffee market.

5 Conclusion

The present strategy included a two-fold evaluation where a guided and non-guided (traditional) evaluation was performed on different days and the samples were randomly introduced to the Q-graders evaluators. With the aid of DOE statistical analysis, it was possible to identify biased evaluations made by the judges, which provided an efficient tool to correctly assess the coffee quality and identify or even reduce the influence of the human factor over this sensory analysis. This evaluation may aid in more confidence in the access quality of the coffee drink by enhancing the precision of the attributed grade.

The present strategy presents an efficient tool that can be used as one of the food control protocols for assessing coffee quality, where the analysis is essential to protect consumers from low-quality products, raise the visibility of high quality local producers, and promote confidence in the coffee analyzed with the present methodology.

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Supplementary Material

Supplementary material accompanies this paper.

Table 1S. Experimental design table with the grades attributed by the six Q-grade evaluators for forty-three samples and two types of quality assessment and the respectively grade for the 516 experiments.

Figure 1S. Grade attributed for the samples by the evaluators using traditional (a) and guided (b) type of quality assessment. The statistical comparison between the way the grade was calculated for each evaluator using the average values for the samples and the t hypothesis test (c).

Figure 2S. Normal qq-plot (a,d) and cumulative distribution (b,e) for the raw data, qq-plot for the DOE model residue (c,f), built with the grades attributed by all the Q-graders (a, b, c) and without the Q-grader that present biased grades (d, e, f).

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