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Coffee Quality Analysis for the Development of Small Producers in Guajiquiro, La Paz, Honduras.

Andrea Gabriela Euseda Valle[1], Leonel Molina Guardiola[2], Ismael Abarca[3]
[1]Universidad Tecnológica Centroamericana (UNITEC)
Boulevard Kennedy, V-782, frente a Residencial Honduras, Tegucigalpa, Honduras andreaeuseda@unitec.edu;
guardilalm@unitec.edu; iabarca@unitec.edu

Abstract **-** This research focuses on understanding the quality of coffee produced in the Guajiquiro region, La Paz, Honduras, an area recognized for its coffee production. Through sensory and physical analyses applied to six coffee samples from five small producers in the area, using cupping. The data obtained were processed through an analysis of variance, which helped identify the key data to understand the quality and variability between the samples. The Guajiquiro region, La Paz, Honduras, is made up of small producers who face challenges such as a lack of resources, tools, and technical knowledge to evaluate the quality of their coffee production, making it difficult to improve their product, affecting their competitiveness and economic development. The results obtained allowed the identification of the determining factors of coffee quality. The variability and significant differences between the samples provide insight into the current state of quality and consistency in the production processes.

Keywords: Coffee tasting, Sensory analysis, Physical analysis, Influencing variables, Design of experiments, Analysis of variance.

1. Introduction

Coffee production is essential to the economy of Honduras, particularly for small producers in the municipality of Guajiquiro, department of La Paz, which is a key region for coffee cultivation. Research conducted in Chiapas, Mexico, highlighted that cultivation techniques affect coffee quality and profitability, emphasizing the importance of systematic controls to improve product quality and competitiveness [1]. A study in Honduras demonstrated the effectiveness of Statistical Process Control (SPC) in reducing variability in bean size and sensory attributes, ensuring coffee quality uniformity [2]. However, advanced quality control methods such as ANOVA and Design of Experiments (DOE) are not systematically used, limiting producers' ability to optimize coffee quality [3]. A study in western Honduras revealed that small coffee producers often face economic difficulties, with limited access to technology and structured quality evaluation methods, reducing their competitiveness in local and international markets [4]. Additional research found that the application of advanced quality techniques directly improves the market value of coffee [5]. Moreover, a national study mapping the coffee value chain highlighted how the lack of information and technology hinders the competitiveness of small producers [6]. To address these challenges, this study aims to use industrial engineering tools, specifically ANOVA and DOE, to assess coffee quality. By identifying factors influencing coffee quality, the research will provide small producers with a practical guide to improve quality, increase competitiveness, and strengthen the sustainability of the Honduran coffee sector.

2. Approach

The approach of this research was quantitative, as it sought to objectively and directly assess the factors and aspects that influence coffee quality in Guajiquiro using experimental design techniques. According to [7], quantitative research aims to obtain numerical and objective data through structured techniques. This approach was ideal for this study, which focused on finding relationships, describing patterns, and performing statistical analysis. This type of approach was appropriate as it was applied in a research study that used experimental design and analysis of variance (ANOVA) to determine the factors influencing coffee quality.

2.1. Scope

This research has an experimental nature, as it employed experimental design and analysis of variance (ANOVA) to manipulate and control variables in the coffee production process and analyze the parameters that directly affect its quality. [8] states that experimental studies are characterized by manipulating variables to analyze their effects on a specific phenomenon. By using an experimental approach, the study analyzed the relationships between various factors and the results obtained, which included both physical and sensory analyses of the coffee samples. The objective was to obtain numerical results and data that could be analyzed to evaluate the impact of the factors on coffee quality.

2.2. Research Variables
2.2.1 Sensory Variables
For the sensory research variables in the sensory analysis evaluated by the taster, the following variables were considered: aroma, flavor, aftertaste, acidity, body, balance, taster score, uniformity, cleanliness, sweetness.
2.2.2 Physical Variables
For the physical research variables, the physical factors analyzed by the taster in the coffee samples were as follows: coffee yield, gold analysis, coffee density, bean size, and the number of imperfections.
2.2.3 Coffee Varieties
Among the coffee varieties to be researched, the type of variety presented in the samples was considered, including IHCAFE 90, Catuai, and Bourbon.

2.3 Instruments
For the instruments used, six coffee samples in cherry form were taken, with a three-pound sack per sample.
2.3.1 Techniques
The techniques used to obtain the results were the following: physical coffee analysis, sensory coffee analysis, and Minitab.

2.4 Population and Sample
2.4.1 Population
The population is limited to five small coffee producers in Guajiquiro, La Paz.
2.4.2 Sampling
The convenience sampling method was used due to the accessibility and availability of the selected coffee producers, as well as the ease of obtaining the required coffee samples. According to [9], convenience sampling involves selecting elements that are more accessible within the research, which is more suitable when specific data is prioritized, and when time or resources are limited.
2.4.3 Sample
Since convenience sampling was used, the sample consisted of six coffee producers due to their easy access and willingness to provide their samples. From each producer, cherry coffee samples were taken, with a total of 3 pounds per sample from each producer, which were then processed into parchment coffee for further analysis.

3. Research methodology
This research used a quantitative approach to assess the factors affecting coffee quality in Guajiquiro, La Paz. Employing Design of Experiments (DOE) and Analysis of Variance (ANOVA), the study sought to control production variables and identify key quality parameters. The study focused on small producers from Guajiquiro, known for their coffee production despite technological challenges. Coffee samples were obtained from five producers chosen at the discretion of the researcher, each providing three pounds of cherry coffee. Figure 1 below shows the methodology applied according to the process diagram.

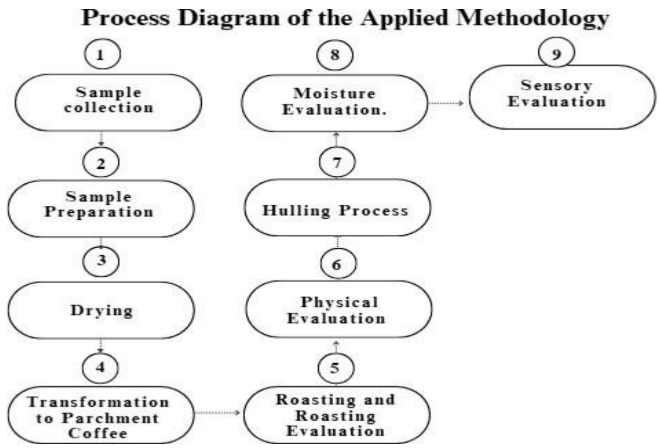

Fig. 1: Process diagram in sequential order for the applied methodology

The coffee underwent the processes of depulping, washing, and sun drying for six hours a day over the course of one week. Once dried, it was processed into parchment coffee and sent to IHCAFE for evaluation. A certified taster evaluated the moisture content, ensuring it was within the 10-12% range. The coffee was then processed into green coffee for physical analysis, including size, shape, color, and defects. Roasting was done according to moisture levels, and the coffee was evaluated using the Agtron scale (55-65) for a medium roast. Sensory evaluation was performed through cupping using the SCA scoring system, with scores for aroma, flavor, aftertaste, acidity, body, uniformity, cleanliness, and sweetness. ANOVA analysis of the data was conducted using Minitab to process and interpret the results for reliable conclusions.

4. Analysis and results

Through the applied methodology, input and response variables were identified. The impact of each variable is reflected through the physical and sensory analyses applied to the samples, evaluated based on the SCA scoring system.

4.1 Influential variables on coffee quality

4.1.1 Input variables

Three input variables were selected for the study to assess coffee quality: moisture percentage, roasting time, and variety type. Each variable was chosen based on its influence on the physical characteristics of coffee, as well as its sensory properties. As input variables, they can affect the response variables by modifying their values depending on the expected results. Figure 2 shows the responses found based on each variable.

Sample	**Humidity percentage (%)**	**Roasting time (min)**	**Coffee variety**
1	10.2	8	IHCAFE 90
2	11.6	12	Catuai
3	10.4	9.43	Bourbon
4	11	11.43	Catuai
5	10.8	10.29	Bourbon
6	10.4	9.5	IHCAFE 90

Fig. 2: Results for input variables for each sample

4.1.2 Response variables

4.1.2.1 Physical variables

In the analyzed samples, variations were found in both yield and the percentage of defective beans. The density of the beans ranged from 703 to 760 g/L, indicating differences in consistency. For bean size, most varieties showed larger and more uniform samples, except for Catuai in sample 1. Similarly, the number of defective beans was low in most of the samples. Figure 3 shows the average found in each category for all samples.

Performance			Average analysis in gold			Average densiry			Average grain size in gold	Average Imperfections
Dry parchment sample	Gold producer	Performance	Producer	Clean	Reject	Gold weight	Volume CC	Density		
500	402.1333333	1.244	350	329.5583333	20.44166667	145.7333333	200	729	11.07722222	16.8442623

Fig. 3: Average Results for Physical Analysis Samples

4.1.2.2 Sensory variables

Sensory variables correspond to characteristics such as taste, aroma, and texture. Since the results depend on the taster, they may be influenced and vary, though they are still considered valid due to being performed by a certified expert. These variations allow for precise results through essential methodologies, determining the perceived quality of coffee. Figure 4 shows the scores obtained for each sample in its different categories.

Sensorial characteristics	Variety					
	IHCAFE 90		Catuai		Bourbon	
	1	2	1	2	1	2
Aroma	8.2	8.7	7.7	8.2	8	8.3
Flavor	8.2	8.7	7.8	8.3	8	8.3
Aftertaste	8	8.75	7.5	8	8	8
Acidity	8.3	8.2	7.8	8.3	8	8
Body	8.3	8	7.8	8.3	8.3	8.3
Balance	8	8	7.8	8	8	8
Tasters score	8	8	7.8	8	8	8
Uniformity	10	10	10	10	10	10
Cleanliness	10	10	10	10	10	10
Sweetness	10	10	10	10	10	10

Fig. 4: Results for sensory variables per sample

4.2 Results through analysis of variance (ANOVA)

An analysis of variance (ANOVA) was applied to evaluate whether differences in sensory ratings were due to coffee varieties and individual sensory characteristics. The results indicated statistically significant differences ($p < 0.05$). These findings align with what was stated [15], where ANOVA helps identify variables that significantly impact coffee quality. Figure 5 shows the design of the variance analysis applied through factorial design.

Fuente	GL	SC Ajust.	MC Ajust.	Valor F	Valor p
Modelo	29	47.8504	1.65001	37.68	0.000
Lineal	11	47.2380	4.29436	98.06	0.000
Análisis sensorial	9	46.7412	5.19347	118.59	0.000
Variedad	2	0.4968	0.24838	5.67	0.008
Interacciones de 2 términos	18	0.6124	0.03402	0.78	0.709
Análisis sensorial*Variedad	18	0.6124	0.03402	0.78	0.709
Error	30	1.3138	0.04379		
Total	59	49.1641			

Fig. 5: Analysis of variance applied through general factorial regression: rating vs. sensory analysis; variety.

4.2.1 Pareto chart of standardized effects.

The Pareto chart shows that the sensory analysis factor (A) has the greatest impact on sensory ratings, while the variety factor (B) is also significant but with lesser influence. These results support the findings of [16], who emphasize the usefulness of tools such as ANOVA and the Pareto chart for identifying key factors affecting coffee quality. Figure 6 shows the relationship between factors.

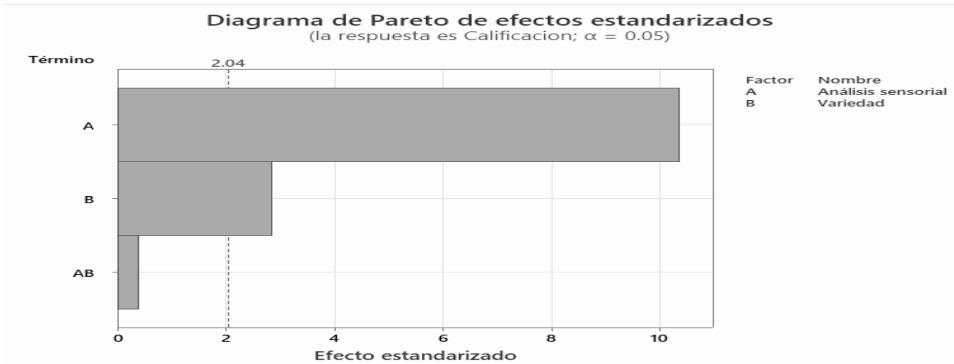

Fig. 6: Pareto chart of standardized effects applied in ANOVA

4.2.2 Bartlett's test for homogeneity variances.

Bartlett's test was applied to validate the homogeneity of variances for the residuals of the model, obtaining a p-value of 0.976. This result confirms that the variances are homogeneous between the levels of sensory analysis and coffee varieties, validating the application of ANOVA and reinforcing that perceived quality is influenced by its sensory attributes. Figure 7 shows the test of equality applied.

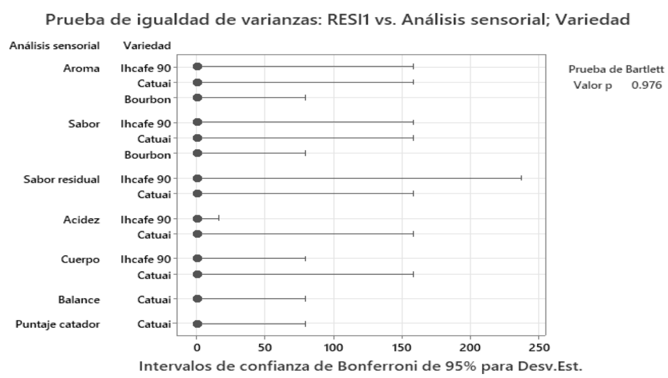

Fig. 7: Test of equality of variances: RESI1 vs. Sensory analysis: Variety

4.2.3 Interaction and effects graph for ratings.

The interaction and effect graph showed that attributes such as cleanliness, uniformity, and sweetness had high and stable scores among the varieties analyzed, indicating consistency in these quality factors. The rest of the sensory attributes varied significantly by variety, suggesting that differences in perceived quality are mainly influenced by the genetic factors inherent in each coffee type. Figure 8 shows the effects and interactions by ratings and attributes.

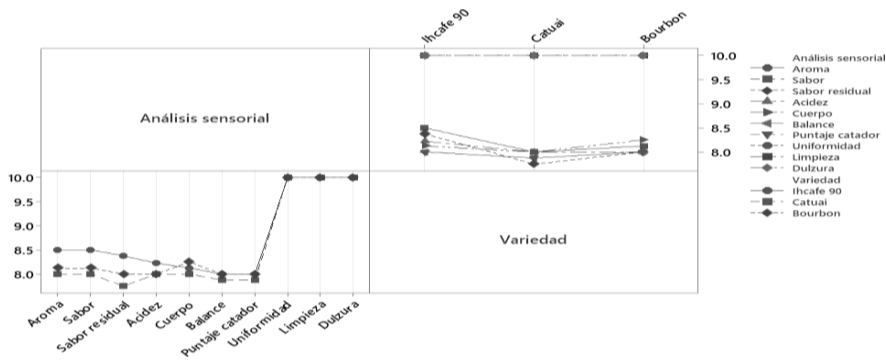

Fig. 8: Effects and interaction chart of ratings

4.3 Quality improvement strategies based on ANOVA results.

To apply the improvement strategy, the variety with the lowest quality ratings was identified. Sample 1 of the Catuai variety had the lowest scores compared to the other evaluated varieties, which differs from [12], where Catuai is reported to have better results compared to IHCAFE 90. In this case, IHCAFE 90 showed the best results, followed by Bourbon. The graph reveals a significant relationship between moisture level, roasting time, and bean color, measured on the Agtron scale. As the moisture percentage increases, roasting time also increases, resulting in a darker bean color, which affects the perceived sensory quality. These results emphasize the importance of controlling the moisture level during the coffee drying process since excessive moisture requires more aggressive roasting, compromising sensory attributes. Figure 9 shows the behavior between variables.

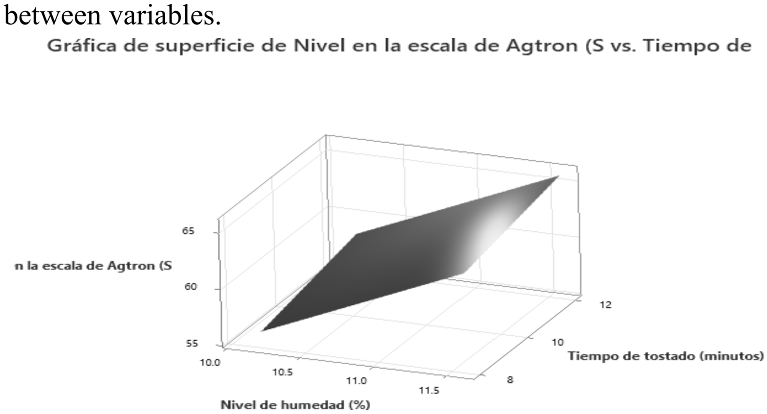

Fig. 9: Surface plot between levels for improvement proposal in input variables

4.4 Expert validation.

To validate the tools used in this study, expert triangulation was performed. Two experts in design of experiments (DOE) validated the proper application of ANOVA and regression analysis, confirming the appropriateness of the experimental design and identifying significant differences between coffee samples. Additionally, a coffee quality expert was consulted, who validated the sensory and physical results, particularly the relationship between moisture, roasting time, and sensory rating, ensuring the relevance of the evaluated variables in the coffee sector.

5. Conclusions

5.1 Overall conclusion

The study determined the quality of coffee produced by the farmers. Through ANOVA, it was found that there are statistically significant differences in the evaluated variables that directly influence quality. The sensory characteristics indicated that IHCAFE 90 had the best performance, with an overall rating of 87 and 87 out of 100. Catuai received global scores of 84 and 87, and Bourbon received scores of 86.25 and 86.75. The samples met the standards established by IHCAFE for high-quality coffee, with quality being influenced by the moisture percentage in each coffee variety.

5.2 Partial conclusions

1. The physical and sensory analyses revealed that the variables most influencing the quality of coffee from Guajiquiro are the moisture of the beans, roasting time, and coffee variety. The moisture percentage is highlighted in this research because not having a standardized moisture percentage for each sample variety influences the quality at the end of the evaluation. For the samples, IHCAFE 90 had moisture percentages of 10.2% and 10.4%. Catuai had moisture percentages of 11% and 11.6%, the highest among all, especially the Catuai sample. Bourbon had moisture percentages of 10.4% and 10.8%, which were like those of IHCAFE 90.
2. The ANOVA analysis showed that there are statistically significant differences in sensory variables and coffee variety. Both variables had p-values lower than the alpha level of 0.05, indicating a significant effect on quality based on variety. Results showed that IHCAFE 90 had an average quality rating between 8.00 and 8.75, outperforming the other varieties. Catuai had average ratings between 7.5 and 8.25, with varying results due to moisture differences between samples. Bourbon had ratings between 8.00 and 8.25, making it the second-best variety of quality.
3. Based on the ANOVA results, it was found that despite the recommended moisture percentages of 10%-12%, some varieties are vulnerable to high moisture levels, even within the recommended range. For Catuai, a very high moisture level of 11.6% influenced its sensory tests, affecting its final quality profile. The other samples, with moisture levels between 10.2%-10.4%, had more consistent roasting levels, allowing them to produce more stable results in aroma and flavor analysis.
4. Expert triangulation validated the effectiveness of the tools used, such as the design of experiments (DOE) and ANOVA, providing an objective and comprehensive view of the validity of the results obtained. Experts agreed that the applied methodologies were appropriate for the coffee quality analysis, reinforcing the variables that influence quality and how they interact with each other. Validation by the coffee expert confirmed that moisture level is the essential factor in evaluating coffee quality, as other variables depend on it.

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