International Journal of Agriculture and Biosciences 2026 15(2): 737-744.
https://doi.org/10.47278/journal.ijab/2025.223

RESEARCH ARTICLE eISSN: 2306-3599; pISSN: 2305-6622

# Commercial Quality of Regional Cacao Genotypes Cropped at Alto Sinú, Córdoba

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## ABSTRACT

Cacao (*Theobroma cacao* L.) is essential for chocolate production and holds significant economic and cultural value. This study evaluated the physical and sensory characteristics of five genotypes grown in Alto Sinú, Córdoba, Colombia. Physical parameters such as grain index, cotyledon percentage, and fermentation index were analyzed following standardized protocols, while a trained sensory panel assessed cacao liquor profiles. Results showed that all genotypes exceeded quality standards, with overall scores ranging from 6 to 8 out of 10. FSV41 stood out for its superior sensory attributes, characterized by nutty, floral, and sweet notes. The beans, classified as large (70–80/100g), are suitable for export and premium chocolate production. The results indicate that genotype, geographical origin and post-harvest processes, such as fermentation, are factors that influence the development of flavor precursor compounds for the final quality of cocoa. In addition, the research highlights the potential of Colombian cocoa in high-quality markets, suggesting that strengthening the production chain through genetic selection and control of post-harvest processes can improve the international competitiveness of the sector, especially with regional genotypes such as FSV41 that present ideal sensory attributes.

**Keywords:** Cacao beans, Sensory quality, Genotype, Sensory profile, Postharvest.

**Article History**
Article # 25-388
Received: 05-Jul-25
Revised: 02-Aug-25
Accepted: 27-Aug-25
Online First: 22-Dec-25

## INTRODUCTION

Cacao beans, including Criollo, Trinitario, and Forastero cacao, are highly demanded products whose quality varies according to their origin and genotype variety (Kongor et al., 2016; Beer et al., 2024). Cacao serves as the primary ingredient in chocolate production and the final quality is predominantly influenced by post-harvest processes, such as fermentation, which generates flavor precursor compounds (Pérez et al., 2021; Ku & Liu, 2024).

Currently, cacao is of significant economic importance on a global scale. The increasing demand for chocolate and cacao-derived products has driven substantial industrial growth. Chocolate is widely regarded as one of the most valued luxury foods owing to its unique functional and sensory properties. The physical quality of cacao beans (*Theobroma cacao* L.) plays a critical role in determining the quality of chocolate and other cacao derivatives. This quality is influenced by factors such as the genotype, geographical origin, and environmental conditions (Pérez et al., 2021). Processing techniques, including fermentation, drying, and roasting, contribute to the development of distinctive flavors and aromas (Djikeng et al., 2018; Pérez et al., 2021).

In Colombia, cacao is a product of high socioeconomic impact, encompassing economic, environmental, and social dimensions. The cacao industry faces challenges such as price volatility, climate change, and sustainability of agricultural practices (Rojas et al., 2022). Colombia is recognized as a producer of fine and aromatic cacao varieties (Rodríguez-Silva et al., 2023), with several genotypes selected by public and private institutions such as Federación Colombiana de Cacaoteros (FEDECACAO), Agrosavia, Nacional de Chocolates and Luker. This study focuses on three widely cultivated genotypes: Colección Castro Naranjal 51 (CCN51), Imperial College Selection 01 (ICS01) and Imperial College Selection 38 (ICS 38); and two regional genotypes Fedecacao

**Cite this Article as:** Quintana-Fuentes L, García-Jerez A and Alvis-Bermúdez A, 2026. Commercial quality of regional cacao genotypes cropped at Alto Sinú, Córdoba. International Journal of Agriculture and Biosciences 15(2): 737-744. https://doi.org/10.47278/journal.ijab/2025.223

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Arauquita 5 (FEAR5) and Fedecacao San Vicente 41 (FSV41), which are representative of the Alto Sinú region in the department of Córdoba, Colombia, according to the census conducted by Fedecacao in 2022.

According to the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), the Ecuadorian CCN51 clone, derived from a cross between ICS95 and IMC 67, produces medium-sized seeds and is recognized for its aroma and balanced flavor. ICS01 and ICS39 belong to the group of Trinitario-origin clones, known for their vigorous growth and favorable morphology. ICS39 is characterized by its morphological stability, physical traits suitable for commercial cultivation, medium seed size, good industrial quality, and favorable sensory characteristics. However, ICS39 exhibits lower specificity during fermentation and roasting processes when compared to CCN51. Overall, these clones are valuable in blends seeking to optimize production, quality, and sensory performance (Phillips Mora et al., 2013; Calva Ríos et al., 2021).

In regional genotypes, FEAR5 produces beans with a grain size index greater than 1.5g in the foothill plains and mountainous areas of Santander. Similarly, FSV41 yields beans exceeding 1.5g (Federación Nacional de Cacaoteros-Fedecacao 2019). FEAR5 is associated with fruity, citrus, and floral notes reminiscent of aromatic herbs, while FSV41 presents a ripe fruit flavor with slightly sweet and pleasant attributes (Federación Nacional de Cacaoteros-Fedecacao, 2020). Moreover, cacao cultivation has emerged as a peaceful and effective alternative for substituting illicit crops and fostering community reconciliation in regions affected by violence (Federación Nacional de Cacaoteros-Fedecacao, 2023), exemplified by municipalities such as Tierralta and Valencia, Córdoba.

The objective of this study was to evaluate the physical characteristics of cacao beans and perform sensory analyses of cacao liquors obtained from five representative genotypes cultivated in Córdoba. This work represents a significant contribution to the understanding of cacao genetic diversity in the region, where information on local genotypes remains limited. Additionally, by assessing both the physical traits of the beans and the sensory profiles of the liquors, this study provides scientific evidence that supports the differentiation of quality attributes within the local context. These findings establish a foundation for future research focused on improving productivity and enhancing the valorization of genotypes with potential for the regional chocolate industry.

## MATERIALS & METHODS

### Fermentation of Cacao

Cacao fermentation is a critical post-harvest process that enhances the quality of cacao beans. It involves the internal transformation of the cotyledon to reduce bitter and astringent flavors, generate precursors for characteristic flavors and aromas, and enhance the overall cacao flavor. Fermentation occurs through semi-solid processes that encompass both anaerobic and aerobic stages (Quintana Fuentes et al., 2018; Fernando et al., 2021; Arulmari & Visvanathan, 2024). The fermentation of cacao includes:

### Harvesting and Preparation

In this step, the fruits are collected and the cacao beans are extracted to be arranged in the fermentation system.

### Fermentation Process

This process lasts between 5 and 7 days, depending on the genotype and fermentation equipment. Microorganisms are the main actors in this process, transforming the grain by generating by-products from biochemical reactions of carbohydrates, proteins, acids, and other substrates. It is important to monitor the temperature, humidity, and pH of cacao. Often, beans are blended during fermentation to ensure uniform fermentation and prevent mold formation (Kongor et al., 2016; Djikeng et al., 2018).

### Drying

Beans are dried in the sun or in artificial dryers to reduce their moisture content. In this step, the water content is lowered by up to 7-7.5% to prevent mold growth and to prepare the grains for storage and transport (Kongor et al., 2016; Fernando et al., 2021; Mougang et al., 2024).

The importance of the fermentation process lies in its role in the development of flavor and aroma precursors. Fermentation has also been shown to reduce cadmium (Cd) concentrations and promote the migration of Cd from the cotyledon to the teste. Additionally, proper control of temperature and pH during fermentation enhances the sensory quality of cacao, directly affecting the flavor and aroma profile of the final product. This process also increases the availability of bioactive compounds and nutrients while producing beans with improved storage stability and a reduced risk of deterioration (Camargo et al., 2024).

### Physical Analysis

The evaluation of the physical characteristics of cacao genotypes and determination of their suitability for the production of cacao-based products was based on the methodology described in Norma Técnica Colombiana (NTC) 1252 (ICONTEC, 2003). The parameters evaluated were grain index (GI), percentage of cotyledons (% TOC), percentage of husk (% CAS), percentage of fermentation (PF), and number of grains in 100g (NG 100g) (ICONTEC, 2003; Ministerio de protección social, 2011; ICONTEC, 2017; Fernando et al., 2021). Physical analysis of the poop grain was performed using several standardized methods described in NTC 1252:2021, NTP-ISO 2451:2021 (ICONTEC, 2021), resolution 1511 of 2011 and The De Zaan (ICONTEC, 2003; ADM Cocoa, 2006; Ministerio de protección social, 2011; ICONTEC, 2017), among others. The methodology for subsequent analyses is described.

### Bean Count

Three hundred g of cacao beans were weighed, and impurities and broken beans were removed. Then, the number of grains per 100g of sample was determined to determine the quality and uniformity of the grains according to NTC 1252:2021, NTP-ISO 2451:2018.

**Cut-off Test**

This test evaluates the degree of fermentation and sanitary quality. The dried cacao beans were cut lengthwise using a MAGRA 14 guillotine and examined under natural light. Characteristics, such as color and texture, were analyzed for well-fermented, half-fermented, unfermented, slate, moldy, and other defects according to NTC 1252:2021, NTP-ISO 2451:2018.

**pH Analysis**

This was performed using 10g of cotyledons mixed with hot distilled water, which was then filtered. pH was measured using a Biobase 210 digital pH meter, according to NTC 1252:2021 y la ISO 1252:2018.

**Moisture Content**

The moisture content of fermented and dried beans was determined using an AGRATRONIX moisture meter, according to NTC 1252:2021 y la ISO 1252:2018.

**Sensory Analysis**

Cacao sensory analysis is a systematic process used to evaluate organoleptic characteristics of cacao beans. This technique focuses on the sensory perceptions that consumer's experience when tasting cacao and its products (Kongor et al., 2016). Sensory analysis allows the identification and evaluation of sensory attributes of cacao, such as flavor, aroma, and texture, which are crucial for classifying cacao. This is essential to meet the demands of national and international markets (ICONTEC, 2014; Fernando et al., 2021). The sensory analysis process began with the post-harvest treatment of the cacao described in the fermentation section. Additionally, it was necessary to pre-select, select, train, and evaluate the training of evaluators who analyzed liquor samples obtained from cacao.

The recruitment, selection, training, and evaluation guidelines were developed based on the provisions established in the Guías Técnicas Colombianas (GTC) and NTC. The following documents were used as references: GTC 165 (ISO 6685:2005), GTC 280 2017 (ISO 8586:2014), NTC 3929, and GTC 226 (ISO 8589:2007) (ICONTEC, 2009, ICONTEC 2012, ICONTEC 2014, ICONTEC, 2017). The procedures were as follows:

- Pre-selection of a group of candidates through a survey (ICONTEC, 2014).
- The selection of training candidates with the application of discriminative tests to determine the ability to detect basic flavors, colors, aromas, and discrimination of differences (ICONTEC, 2017).
- The selected candidates were trained in basic flavor patterns, special flavors, and acquired flavors for cacao beans.
- Training of evaluators to establish their suitability for liquor evaluation tests.
- NTC 3929 was selected as a standard for the evaluation of the flavor and aroma profile of cacao liquor samples (ICONTEC, 2009, 2020).

Cacao liquor samples were prepared as follows. The moisture content and number of beans per 100 g of cacao were evaluated to determine the optimal roasting conditions for each genotype. Roasting was conducted within a temperature range of 120–130°C for 20–25 min using a CACAOTOWN rotary roaster (Djikeng et al., 2018; Cacao of Excellence, 2023). After roasting and cooling, the cacao beans were ground, and the husks were separated to minimize the presence of this by-product. The grinding process was performed using a CACAOTOWN stone mill until a particle size of at least 20μm was achieved (Cacao of Excellence, 2023). The ground cacao was molded and stored at a temperature below 8°C until the sensory evaluation phase (Camargo et al., 2024).

The cacao liquors were melted at 55±0.1°C and transferred into covered containers before being presented to a trained sensory evaluation panel. Sensory attributes, such as astringency, bitterness, acidity, and specific and acquired flavors, were assessed in several sessions following the NTC 3929 guidelines (Cacao of Excellence, 2023; Camargo et al., 2024). The evaluation scale for each sample ranged from 0 to 10, corresponding to a descriptive test under the framework of the NTC 3929. The evaluation sheet included three criteria: attribute quality, residual flavor, and overall rating, along with detailed observations. The sensory attributes were classified as cacao, astringent, bitter, acidic, sweet, fruity, floral, nutty, green and potential contaminants. The sensory profile of each cacao liquor sample was determined by assessing its basic and specific flavor attributes using a panel of trained sensory evaluators. The sensory analysis results were validated by comparing them with evaluations conducted using the AGROSAVIA sensory panel. Consolidated data were used to generate the technical sensory sheets for each genotype.

Data from the evaluations were statistically analyzed to identify significant patterns and differences among the cacao hybrids and their sensory profiles. Multivariate principal component analysis (PCA), analysis of variance (ANOVA), and multiple comparison tests were performed to determine the statistical significance of observed differences (Kongor et al., 2016; Ku & Liu, 2024).

## RESULTS

**Physical Characteristics**

**pH Monitoring**

The pH was monitored during the 48-hour anaerobic phase and every 24 h on the following days at the time of the turnovers to ensure the incorporation of air into the aerobic phase. Using the box fermentation method, cacao beans showed adequate pH evolution, from higher values of 6 to 7 to values between 4.5 and 5.0 (Fig. 1).

Once the cacao beans were dried with moisture values between 7 and 7.5%, the pH was evaluated, where an average between 4.5 and 5.5 was obtained (Fig. 2). These pH ranges confirmed adequate transformation during the fermentation process, indicating that a five-day fermentation process is adequate, with two days of anaerobic fermentation and three days of aerobic fermentation. This aligns with findings by (Rodríguez-Silva et al. 2023; Arulmari and Visvanathan 2024; Fuentes et al. 2015).

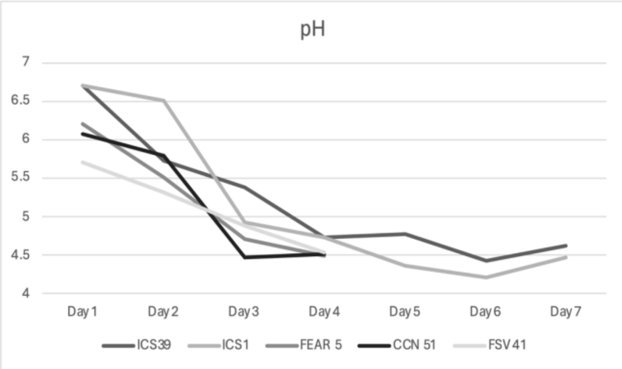


**Fig. 1:** pH monitoring cacao beans during the fermentation process.

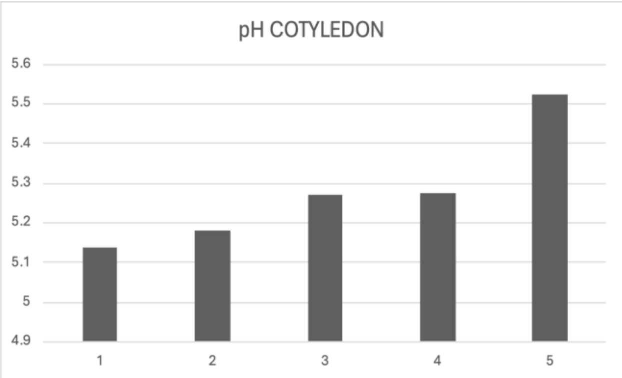


**Fig. 2:** Monitoring pH values for dry cotyledon.

### Percentage of Fermentation

Determination of the percentage of fermentation confirmed that the process carried out in the crates was adequate. Fig. 3 shows the high fermentation rates for the genotypes studied. The transformation of the cacao bean was sufficient for generating precursors of flavor and aroma. It was not necessary to maintain the process for more than five days, which minimized the appearance of fungi in the grain and the generation of unpleasant flavors (Quintana-Fuentes et al., 2016; Rodríguez-Silva et al., 2023). All genotypes reached an index above 80%, confirming adequate fermentation while noting the potential risk of microorganism proliferation that could impact sensory quality.

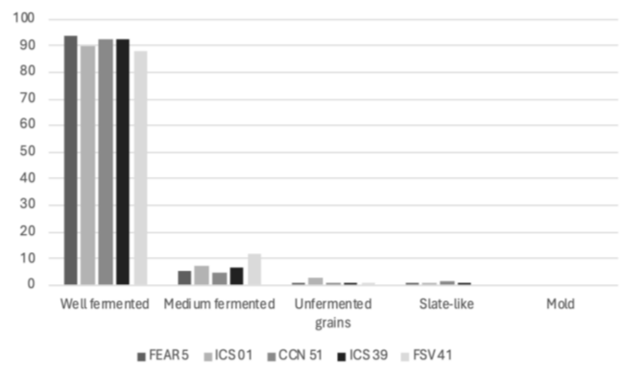


**Fig. 3:** Fermentation rates of cacao genotypes.

### Number of Grains and Grain Indices

The expected results regarding the physical quality of cacao beans may vary depending on the type of cacao, growing conditions, and processing. Fig. 4 shows that all genotypes studied exceeded the large size established in NTC 1252 and ISO 2451:2017 (ISO 2017) for export. NG100g confirmed that the evaluated genotypes produced large grains (70–80grains/100g) that are ideal for export.

Fig. 5 presents another index for national trade in Colombia, which corresponds to the grain index, allowing for the categorization of productivity by genotype. All genotypes were in ranges higher than 1.3, enabling their classification into medium-large beans according to FEDECACAO guidelines.

The GI and % CAS results allowed us to classify the genotypes in the medium GI range as per FEDECACAO's guidelines (Rojas Ardila et al., 2015), with a range of 1.30g to 1.60g. The % CAS was consistent with the grain size, ranging from 14% to 17%. Additionally, the FP was between 80% and 90%, indicating that cacao beans complied with the premium category established in NTC 1252. These results were consistent with studies conducted by (Quintana-Fuentes et al., 2016, Perea et al., 2017; Rodríguez-Silva et al., 2023), underscoring the importance of physical quality in producing high-grade chocolate.

### Sensory Characteristics

### Group of Sensory Evaluators

The established methodology structured a panel of sensory evaluators in training in accordance with the GTC 280:2017. During the training phase, several sessions were conducted to familiarize panelists with the descriptive terms and rating scales used in the sensory evaluation. The effectiveness and reliability of the training were validated through PCA, which allowed for the identification of cohesion and differentiation among panelists' assessments. This ensured that their performance was consistent and representative of the specific sensory characteristics of the evaluated cacao liquors (Kemp et al., 2018).

The final group comprised 32% of the members selected in the initial evaluation process according to NTC guideline 3929:2022 (Fig. 6). Five evaluators trained during this research in accordance with GTC 280 and NTC 3929 analyzed each cacao liquor sample. Consolidation of sample profiles was performed by consensus.

### Sensory Profiles

The sensory profiles for each genotype were obtained. The cacao flavor was highlighted as predominant in a range of five to six, with notes of special attributes, such as nutty, nuts, floral, and sweet, ranging from one to four. Among the five genotypes evaluated, FSV41 received the best rating, with an overall score of 8, as shown in Fig. 7.

The evaluation of the flavor and aroma profiles concluded that the FSV41 regional genotype achieved an overall score of 7.5, while FEAR5 scored 5.6. The CCN51, ICS01, and ICS39 genotypes obtained intermediate values, making them suitable for use in manufacturing fine chocolates (Fig. 8).

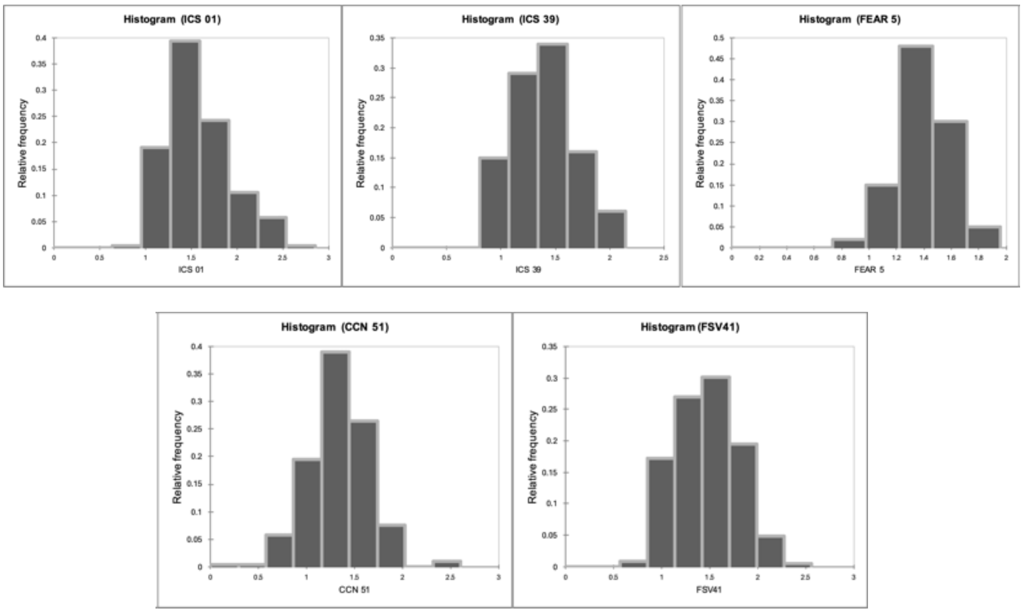


**Fig. 4:** Number of grains per genotype per 100g.

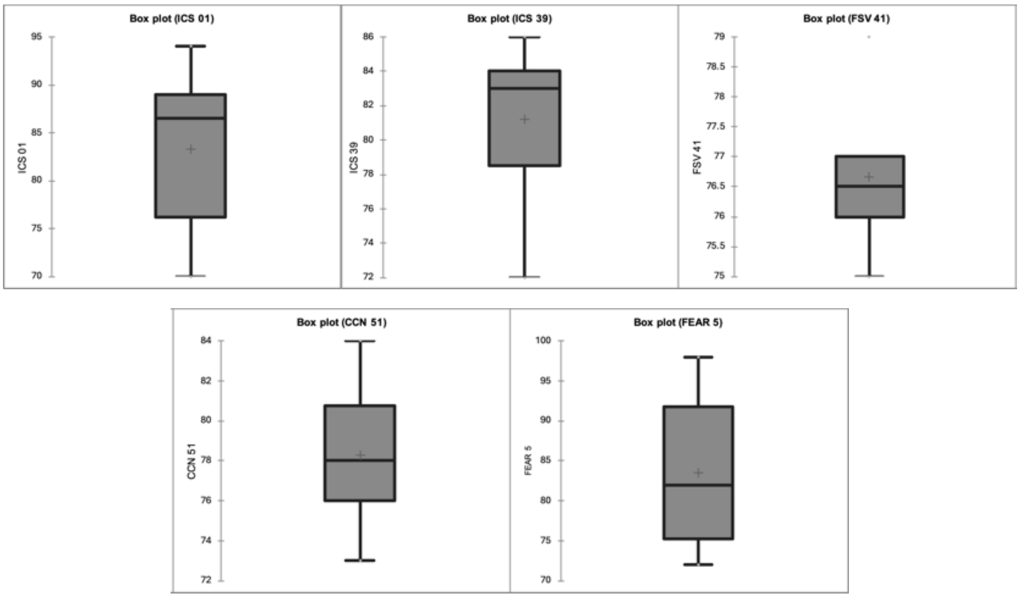


**Fig. 5:** Grain index by genotype.

**Fig. 6:** Group of sensory evaluators during training.

PCA indicated that groups could be observed according to the attributes studied for each genotype (Fig. 9). The FSV41 genotype was associated with fruity, sweet, and nutty attributes, making it unique. Meanwhile, CCN51, ICS01 and ICS39 shared these characteristics alongside basic flavors, such as acidity. FEAR5 exhibited bitter and astringent attributes, correlating with its overall lower rating. Similar findings were reported for CCN51, which demonstrated notable bitter and cacao flavors (Alexandre et al., 2018; Camargo et al., 2024).

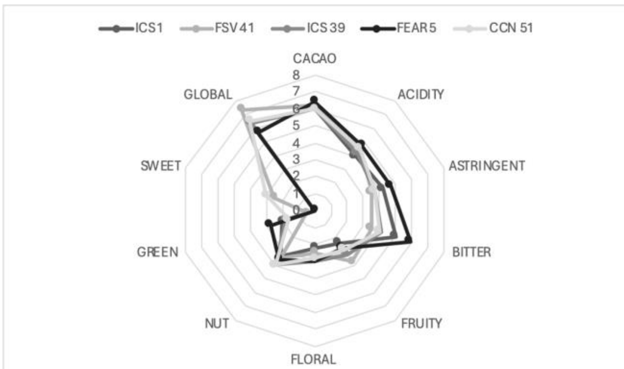


**Fig. 7:** Radial graph of sensory profiles of the studied genotypes.

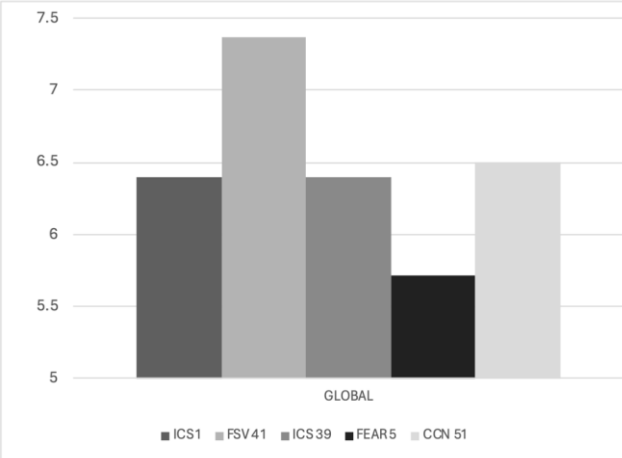


**Fig. 8:** Global cacao liquor study genotypes.

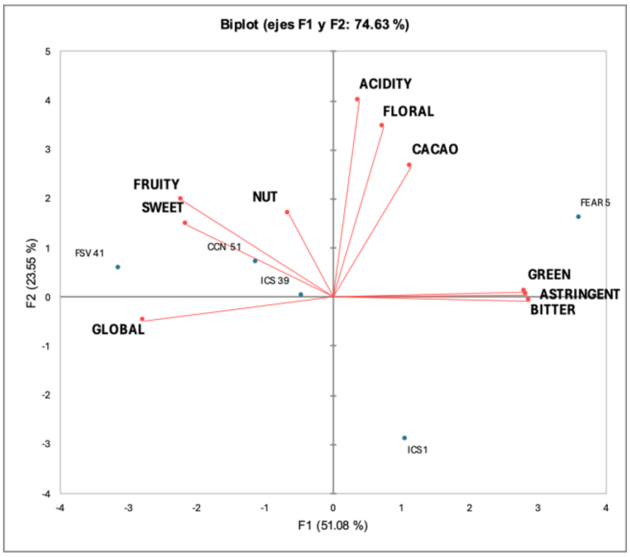


**Fig. 9:** Principal component analysis of cacao liquor for the genotypes studied.

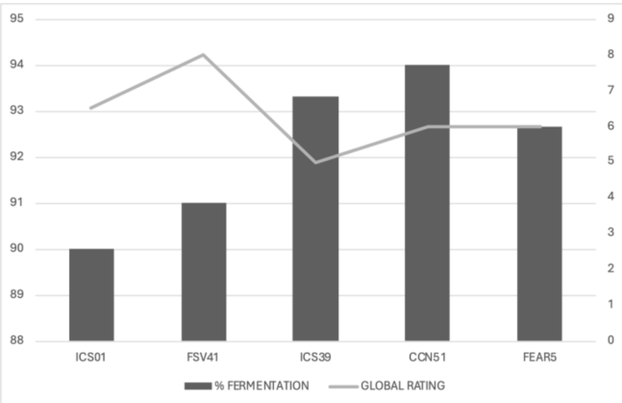


**Fig. 10:** Fermentation index ratio with global rating.

### Global Rating Versus Fermentation Index

Fig. 10 presents the fermentation index and overall rating according to the number of fermentation days. Variations in fermentation time and pH control were crucial for determining the sensory quality of cacao, influencing characteristics such as aroma and flavor. These attributes have a direct impact on quality criteria, emphasizing the need for monitoring fermentation processes to obtain high-quality cacao beans (Mougang et al., 2024).

### Type of Quality

The five genotypes studied qualified as premium cacao according to NTC 1252, complying with the minimum values (Table 1).

**Table 1:** Physicochemical requirements for cacao bean NTC 1252:2021

| Type of cacao | Premium/Special | Standard | Stream |
|---|---|---|---|
| Humidity % | 7.0 | 7.5 | 7.5 |
| Mass (weight) 100g | > 120 | 95 – 120 | < 95 |
| % insufficiently fermented grains | 30 | 35 | 40 |
| % well-fermented grains | 70 | 65 | 55 |

Source: NTC 1252:2021

## DISCUSSION

The findings highlight the critical role of controlled fermentation and drying processes in enhancing the physical and sensory attributes of cacao beans. The observed pH evolution, from initial values of 6 to 7 to final values between 4.5 and 5.5, confirms the efficiency of the five-day fermentation process. This timeline, comprising two anaerobic and three aerobic days, aligns with optimal conditions reported by Quintana-Fuentes et al. (2016) and Rodríguez-Silva et al. (2023), and it minimizes fungal proliferation while ensuring the development of flavor precursors.

The high fermentation rates (>80%) across all genotypes validate the adequacy of the postharvest process. These rates not only confirm proper transformation of the cacao beans but also reflect compliance with premium export standards, such as those defined in NTC 1252 and FEDECACAO guidelines. Moreover, the large bean sizes (70–80 grains per 100g), favorable grain index (GI>1.3) and agroclimatic adaptation further underscore the suitability of these genotypes for both national and international markets. As well as research focused on productive improvement to strengthen the competitiveness and innovation of the chocolate industry in the region.

The CCN51 clone is characterized by a significantly larger seed size compared to the other clones, which affects its fermentation and roasting requirements. In the case of ICS-01 and ICS-39, although specific values are not explicitly detailed in the referenced sources, it is inferred that these clones exhibit intermediate to medium grain sizes, similar to other Trinitario clones selected by Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), with favorable morphological traits for handling and processing (Phillips Mora et al., 2013). The study indicates that the CCN51 clone has a medium grain index ranging between 1.4 and 1.6g, as classified by Perea et al. (2017). Additionally, it reports an average grain index of approximately 1.6g, with a range between 1.2 and 1.7g, suggesting that CCN51 displays consistent grain size unaffected by altitude in the study area (Fuentes et al., 2015).

Technical documents related to regional cacao materials indicate that in areas such as the Santanderena mountain region and the Llanos, which share agroecological conditions with the humid tropical forest zone where this study was conducted, the FEAR5 and FSV41 genotypes exhibit large grain indices, consistently producing beans with average sizes above 1.5g (Federación Nacional de Cacaoteros-Fedecacao 2019). Furthermore, the sensory descriptions for these regions closely align with the results obtained in this study. FEAR5 is characterized by delicate fruity, citrus, and floral notes reminiscent of aromatic herbs, which gradually soften and give way to an excellent cacao flavor. FSV41, on the other hand, presents a ripe fruit flavor that is slightly sweet, smooth, and pleasant (Federación Nacional de Cacaoteros-Fedecacao, 2020).

Sensory evaluations revealed notable genotype-specific differences in flavor and aroma profiles. FSV41, with its fruity, sweet, and nutty attributes, received the highest overall rating (8.0), marking it as an ideal candidate for premium chocolate production. The CCN51, ICS01 and ICS39 genotypes showed intermediate sensory characteristics that also make them suitable for the manufacture of good quality chocolates. In contrast, FEAR5, characterized by bitter and astringent attributes, scored lower, reflecting the impact of genotype on sensory quality. The PCA analysis reinforced these distinctions, grouping genotypes based on their unique sensory attributes (Perea Villamil et al., 2017; Herrera-Rocha et al., 2021).

The relationship between fermentation parameters and sensory attributes further emphasizes the need for precision in postharvest processing. Variations in fermentation time and pH control significantly influence key sensory traits, such as aroma and flavor (Mougang et al., 2024). These results highlight the necessity of continuous monitoring and optimization of fermentation processes to achieve high-quality cacao suitable for premium markets. This study reaffirms the interconnectedness of physical quality, sensory characteristics and market potential for cacao beans, aligning with global standards such as Codex Alimentarius CXS 141-1983 and insights from Bioversity International (Cacao of Excellence, 2023).

### Conclusion

The physical and sensory qualities observed in these genotypes align with findings from studies conducted in other cacao-producing regions, such as the Santander mountains, dry inter-aden valley, lower-middle coffee zone, and humid tropical forest. The results indicate that the genotypes studied exhibit high physical and sensory qualities, making them suitable as fine and aromatic cacao beans. These genotypes can be locally transformed into high-quality products, thereby increasing added value for producers.

The postharvest process is critical for ensuring the final quality of cacao. Proper classification, time management, temperature control, and monitoring of fermentation phases are essential to consistently achieve the desired attributes, such as flavor, texture, color, and safety. These attributes meet the requirements for both domestic consumption and exports, adhering to national standards, CODEX guidelines, and the specific regulations of importing countries.

Fermentation plays a pivotal role in flavor development, enhances bioactive compounds and nutrient bioavailability, and ensures the proper conservation and storage of beans. Therefore, training in these post-harvest processes is vital to strengthen research efforts and improve the quality and competitiveness of cacao products.

## DECLARATIONS

**Funding:** This work was supported by MINCIENCIAS research project "Desarrollo de la cadena productiva de cacao a través del mejoramiento de la calidad e inocuidad y agregación de valor en el departamento de Córdoba" BPIN2020000100380.

**Acknowledgement:** The authors acknowledge the commitment of the cacao community of Valencia and Tierralta, the Universidad Nacional Abierta y a Distancia (UNAD) and the Universidad de Córdoba.

**Conflict of Interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Data Availability:** All the data are available in the article.

**Ethics Statement:** Not required, as this study did not involve any live-animal or human study segments.

**Author's Contribution:** All authors contributed equally to the conception, execution, data collection, data analysis, and writing of the manuscript and critically revised the manuscript, and approved the final version.

**Generative AI Statement:** The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

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## REFERENCES

ADM Cocoa (2006). *The De Zaan ® Cocoa Manual* (1st Ed). Wormer, Netherlands: ADM Cocoa.

Alexandre, A., Lucas F.Q., Jose M.V., & Alberto, G. (2018). Selection of Judges to Train Sensorally in the Cacao Cataction in the Sena Center of Attention to the Santander Regional Agricultural Sector. *Advance Journal of Food Science and Technology*, *15*(SPL), 230–232. https://doi.org/10.19026/AJFST.14.5900

Arulmari, R., & Visvanathan, R. (2024). Effect of Fermentation Methods and Turning Interval on the Quality of Cocoa Beans (Theobroma cacao). *Agricultural Research*, *13*(3), 586–598. https://doi.org/10.1007/S40003-024-00715-9

Beer, J., Bonnemann, A., Chavez, W., Fassbender, H.W., Imbach, A.C., & Martel, I. (2024). Cuantificación de biomasa en sistemas cacaoteros (Theobroma cacao L.) de la provincia Duarte, República Dominicana. *Revista Cubana de Ciencias Forestales*, *12*(3), 229–249. https://doi.org/10.1007/BF00137286

Cacao of Excellence (2023). *Guide for the Assessment of Cacao Quality and Flavour*. Alliance of Bioversity International and CIAT.

Calva Ríos, A.A., Pozo Núñez, C., Dahua Shiguano, B., Ramírez Torres, P., Quiroz Vera, J., Ríos Arrobo, N., López Ulloa, M., Cianferoni, A., & Proaño, A. (2021). *Catálogo de clones de cacao sobresalientes recomendados para la provincia de Napo*. Instituto Nacional de Investigaciones Agropecuarias (INIAP); GIZ.

Camargo, I.D., Rodriguez-Silva, L.G., Carreño-Olejua, R., Montenegro, A.C., & Quintana-Fuentes, L.F. (2024). High temperature and nib acidification during cacao-controlled fermentation improve cadmium transfer from nibs to testa and the liquor's flavor. *Scientific Reports 2024 14:1*, *14*(1), 1–16. https://doi.org/10.1038/s41598-024-62609-8

Djikeng, F.T., Teyomnou, W.T., El Tenyang, N., Tiencheu, B., Morfor, A.T., Arnaud, B., Touko, H., Houketchang, S.N., Boungo, G.T., Sri, M., Karuna, L., Ngoufack, Z., Macaire Womeni, H., Azia, T., Morfor, B., Arnaud, H., Touko, N., Houketchang, G.T., Boungo, M., Touko, N., Houketchang, G.T., Boungo, M, & Macaire, W. (2018). Effect of traditional and oven roasting on the physicochemical properties of fermented cocoa beans. *Heliyon*, *4*, e00533. https://doi.org/10.1016/j.heliyon.2018

Djikeng, F.T., Teyomnou, W.T., Tenyang, N., Tiencheu, B., Morfor, A.T., Touko, B.A.H., Houketchang, S.N., Boungo, G.T., Karuna, M.S.L., Ngoufack, F.Z., & Womeni, H.M. (2018). Effect of traditional and oven roasting on the physicochemical properties of fermented cocoa beans. *Heliyon*, *4*(2), e00533. https://doi.org/10.1016/J.HELIYON.2018.E00533

Federación Nacional de Cacaoteros-Fedecacao (2019). *Caracterización de materiales registrados por Fedecacao*. Bogotá, Colombia: Federación Nacional de Cacaoteros

Federación Nacional de Cacaoteros-Fedecacao (2020). *Perfiles sensoriales y compuestos de interés de materiales de cacao desarrollados por Fedecacao.* Bogotá, Colombia: Federación Nacional de Cacaoteros

Federación Nacional de Cacaoteros-Fedecacao (2023). *Cacao, esencial en reforma agraria y en sustitución de cultivos ilícitos: ministra de Agricultura*. Bogotá, Colombia: Federación Nacional de Cacaoteros

Fernando, L., Fuentes, Q., & García Jerez, A. (2021). Evaluación integral de la calidad sensorial del cacao. *Sello Editorial UNAD*. https://doi.org/10.22490/9789586517782

Fuentes, L.F.Q., Castelblanco, S.G., Jerez, A.G., & Guerrero, N.M. (2015). Caracterización de tres índices de cosecha de cacao de los clones CCN51, ICS60 e ICS 95, en la montaña santandereana, Colombia. *Revista de Investigación Agraria y Ambiental*, *6*(1), 252-265. https://doi.org/10.22490/21456453.1284

Herrera-Rocha, F., Cala, M.P., Aguirre Mejía, J.L., Rodríguez-López, C.M., Chica, M.J., Olarte, H.H., Fernández-Niño, M., & Gonzalez Barrios, A.F. (2021). Dissecting fine-flavor cocoa bean fermentation through metabolomics analysis to break down the current metabolic paradigm. *Scientific Reports 2021 11:1*, *11*(1), 1–18. https://doi.org/10.1038/s41598-021-01427-8

ICONTEC (2003). *NTC 1252: Cacao en grano* (3.ª act), Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC), Bogotá, Colombia.

ICONTEC (2009). *NTC 3929: Cacao en grano* (1.ª act), Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC), Bogotá, Colombia.

ICONTEC (2014). GTC 165: Análisis sensorial. Metodología. Guía general (1.ª act), Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC), Bogotá D.C., Colombia.

ICONTEC (2017). GTC 280: Análisis sensorial. Directrices para la selección, entrenamiento y seguimiento de evaluadores sensoriales seleccionados y expertos. Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC), Bogotá D.C., Colombia.

ICONTEC (2020). GTC 232: Análisis sensorial. Metodología. Guía general para el establecimiento de un perfil sensorial, Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC), Bogotá D.C., Colombia.

ICONTEC (2021). *Cacao en grano* (5.ª act). Instituto Colombiano de Normas Técnicas y Certificación (ICONTEC), Bogotá, Colombia: ICONTEC.

ISO (2017). ISO 2451:2017: Cocoa beans — Specification and quality requirements (3rd Ed), International Organization for Standardization.

Kemp, S.E., Hort, J., & Hollowood, T. (2018). *Descriptive Analysis in Sensory Evaluation*. Hoboken, NJ, USA: Wiley-Blackwell. https://doi.org/10.1002/9781118991657

Kongor, J.E., Hinneh, M., de Walle, D. Van, Afoakwa, E.O., Boeckx, P., & Dewettinck, K. (2016). Factors influencing quality variation in cocoa (Theobroma cacao) bean flavour profile — A review. *Food Research International*, *82*, 44–52. https://doi.org/10.1016/J.FOODRES.2016.01.012

Ku, M.C.Y., & Liu, S.Q. (2024). Unveiling the cocoa-carob flavour gap in dark chocolates via instrumental and descriptive sensory analyses. *Food Research International*, *195*, 114992. https://doi.org/10.1016/J.FOODRES.2024.114992

Ministro de la Protección Social (2011). *Resolución 1511 de 2011*. Bogotá, Colombia: Ministerio de la Protección Social.

Mougang, N.N., Tene, S.T., Zokou, R., Kohole, H.A.F., Solefack, E.N., Ntongme Mboukap, A., Abaoabo, A.A.F., & Womeni, H.M. (2024). Influence of fermentation time, drying time and temperature on cocoa pods (Theobroma cacao L.) marketability. *Applied Food Research*, *4*(2), 100460. https://doi.org/10.1016/J.AFRES.2024.100460

Perea Villamil, A., Martínez Guerrero, N., & Aranzazu Hernández, F. (2017). *Características de calidad del cacao de Colombia*. Bucaramanda, Colombia: Universidad Industrial Santander.

Perea, J.A., Martínez, N., Aranzazu Hernández, F., & Cadena Cala, T. (2017). Características de la calidad del cacao: Catálogo de 26 cultivares. Federación Nacional de Cacaoteros (Fedecacao).

Pérez, M., Lopez-Yerena, A., & Vallverdú-Queralt, A. (2021). Traceability, authenticity and sustainability of cocoa and chocolate products: a challenge for the chocolate industry. *Critical Reviews in Food Science and Nutrition*, *62*(2), 475–489. https://doi.org/10.1080/10408398.2020.1819769

Phillips Mora, W., Arciniegas Leal, A., Mata Quirós, A., & Motamayor Arias, J.C. (2013). *Catálogo de clones de cacao seleccionados por el CATIE para siembras comerciales* [Manual Técnico]. Turrialba, Costa Rica: Centro Agronómico Tropical de Investigación y Enseñanza (CATIE).

Quintana Fuentes, L.F., García Jerez, A., & Moreno Martínez, E. (2018). Perfil sensorial de cuatro modelos de siembra de cacao en Colombia. *Entramado*, *14*(2), 256–268. https://doi.org/10.18041/1900-3803/ENTRAMADO.2.4756

Quintana-Fuentes, L.F., Gómez-Castelblanco, S., García-Jerez, A., & Martínez-Guerrero, N.C. (2016). Creation of a panel of judges in training for sensory analysis of cocoa liquor obtained from different models planting. *Entramado*, *12*(2), 220–227. https://doi.org/10.18041/1900-3803/ENTRAMADO.2.445

Rodríguez-Silva, L.G., Quintana-Fuentes, L.F., Coronado-Silva, R.A., García-Jerez, A., Báez-Daza, E.Y., & Agudelo-Castañeda, G.A. (2023). Caracterización física y sensorial de 24 genotipos especiales de cacao Theobroma cacao. *Revista U.D.C.A Actualidad & Divulgación Científica*, *26*(1). https://doi.org/10.31910/RUDCA.V26.N1.2023.2410

Rojas Ardila, J., Rojas, F., Ramírez, Ó.D., Moreno, F., Castro, G.A., & Pinzón Useche, J.O. (2015). *Guía técnica para el cultivo del cacao* (6th ed.). https://repository.agrosavia.co/handle/20.500.12324/11685

Rojas, M., Hommes, A., Heeres, H.J., & Chejne, F. (2022). Physicochemical Phenomena in the Roasting of Cocoa (*Theobroma cacao* L.). *Food Engineering Reviews 2021 14:3*, *14*(3), 509–533. https://doi.org/10.1007/S12393-021-09301-Z