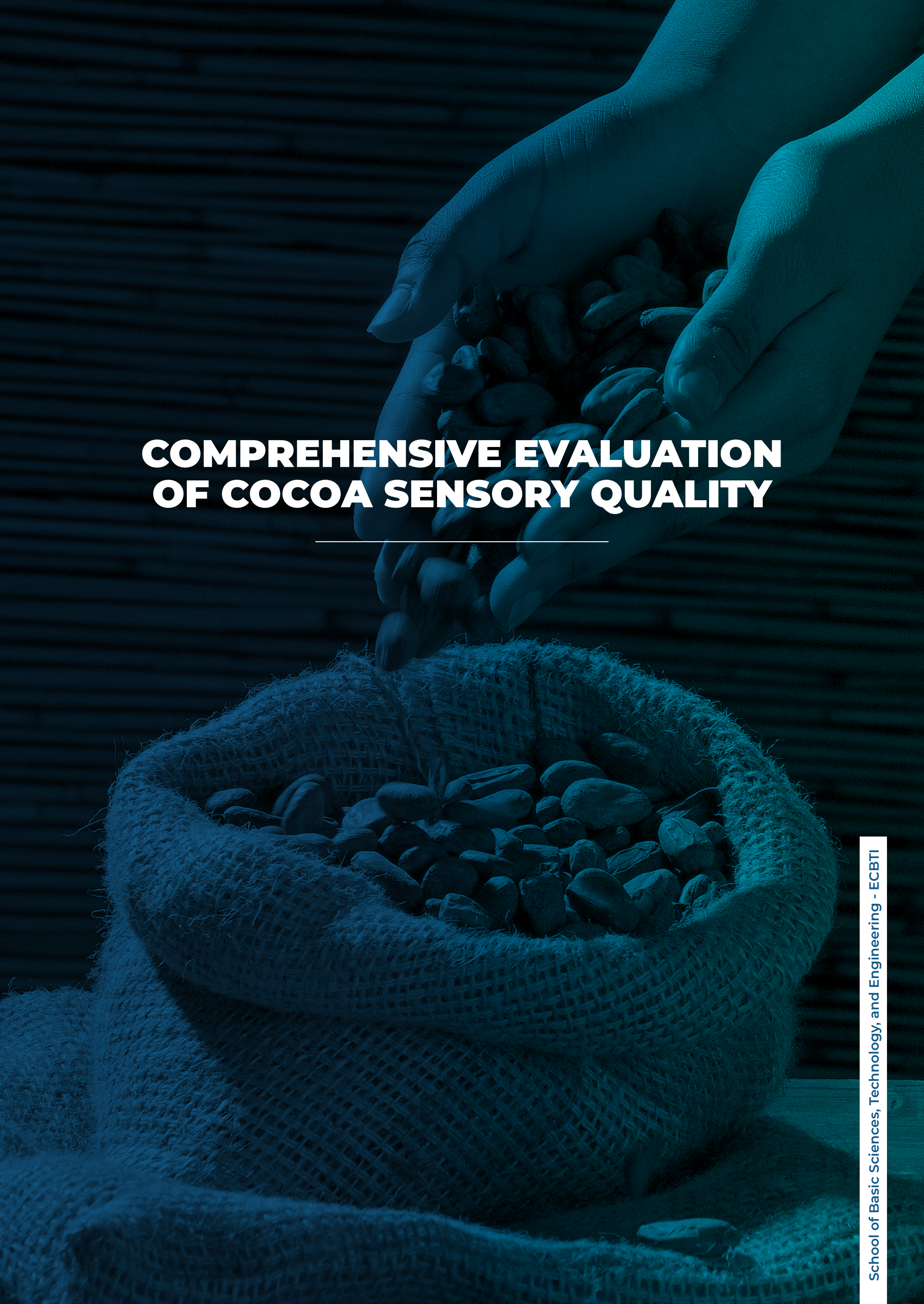

COMPREHENSIVE EVALUATION OF COCOA SENSORY QUALITY

School of Basic Sciences, Technology, and Engineering - ECBTI

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Abierta y a Distancia

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Research Group: Food and Agriculture Research Group of the Universidad Nacional Abierta y a Distancia (GIAUNAD in Spanish)

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PREFACE

Quality is the consumer's expectation that a product will adequately and acceptably meet a need. Thus, the food industry must guarantee 100% product quality, as any lower level of quality could jeopardize safety and the opportunity for customer loyalty.

An example of this is the quality control of cocoa, a food product with high consumption potential and a wide range of derived products in the pharmaceutical, cosmetic, and food industries. This increasing demand has led to various initiatives to increase the production of special cocoa based on its origin or quality.

With this in mind, this book presents five chapters designed to help readers acquire or reinforce their knowledge about cocoa quality in a simple way. It starts with general information about cocoa and explores three critical aspects of any food product: its physical, chemical, and sensory quality. The post-harvest process is also discussed, as it has a significant impact on the final quality of cocoa beans for producing table chocolate, fine chocolate, and confectionery. It also examines key issues in the physical assessment of dried cocoa beans during marketing. Additionally, the book explains sensory quality evaluation as a food science and provides guidance for the development of objective final quality ratings of cocoa liquor obtained from dried cocoa beans.

The authors hope that you enjoy this book and that it will contribute to the development of the cocoa-producing sector. We look forward to a future publication on the exciting topic of transforming dry cocoa beans.

Lucas Fernando Quintana Fuentes
Alberto García Jerez

PRESENTATION

Dear reader, we are pleased to present the book Comprehensive Evaluation of the Sensory Quality of Cocoa, which provides theoretical and practical tools for cocoa producers in Santander, in particular, and for actors in the Colombian cocoa supply chain in general. The aim is to qualitatively and quantitatively assess the quality of cocoa produced in Colombia and thus contribute to strengthening the national cocoa sector.

This book is scientifically framed in the efforts of the researchers, members of the Food and Agriculture Research Group of the Universidad Nacional Abierta y a Distancia (GIAUNAD in Spanish) who have spent a decade studying cocoa quality in Santander and Colombia.

As a result of this research, the book is structured into five chapters. The first chapter covers general information about cocoa. The second one describes the product's harvest and post-harvest processes. The third one specifically addresses the quality of dried cocoa beans before processing them into different chocolate and confectionery products. The fourth chapter presents the fundamentals necessary for assessing the final physical quality of cocoa beans. Finally, the fifth chapter outlines the process for analyzing the sensory quality of cocoa and offers recommendations for the qualitative assessment of cocoa liquor.

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CHAPTER 1

COCOA

The cocoa plant (*Theobroma cacao*) is a neotropical species (tropic region of the Americas) native to the Amazon basin. In the last 30 years, cocoa cultivation has expanded throughout this region to about 20 degrees north latitude and 20 degrees south latitude

The *Theobroma cacao L*. tree originates in the upper Amazon River basin in South America. In the upper Amazon regions of Peru, Ecuador, Colombia, and Brazil, and along the riverbanks of several important river networks flowing into the Marañon and Amazon rivers, several cocoa species are found. Among these, the *Theo-broma* and the subspecies *Theobroma cacao* stand out (Zhang et al., 2009).

It is also known that native groups in Central America, such as the Nahuatl and the Toltecs, who likely traded cocoa with the Incas in the south during pre-Columbian era, placed great importance on its cultivation. Cocoa was consumed as a beverage by the upper class of these cultures, during religious ceremonies, as a medicinal substance, and even as a tribute to the main lords (Becker, 2008).

Figure 1 shows the distribution of indigenous peoples in Central America who used cocoa as a beverage.

Figure 1.

Mesoamerican Region: Southern Mexico and Territories of Nicaragua, Costa Rica, Honduras, El Salvador, and Belize

Source: Becker (2008).

Although native to South America, *Theobroma cocoa* achieved a high level of domestication in Central America. It was there that Spanish conquerors learned about the cocoa plant and its uses. It was later introduced to Europe in the 16th century, thus becoming known to the rest of the world (McNeil, 2006).

Dendrologically speaking, cocoa is a robust, vertically growing woody tree belonging to the Malvaceae family. Its leaves are broad and elongated, and they appear alternately and oppositely on the branches. The cocoa tree (*Theobroma cacao*) has a small genome of 390 Mb and 2n = 2x = 20 chromosomes (Wickramasuriya & Dunwell, 2018). The cocoa tree belongs to a cauliflory species, that is, its flowers and fruits are inserted on the trunk in the oldest branches. The flowers can be found along the trunk and branches in the woody parts of the tree, in groups, forming what are known as "flower cushions." The timing and quantity of flowers is affected by and dependent on climatic changes for their appearance (Claus et al., 2018).

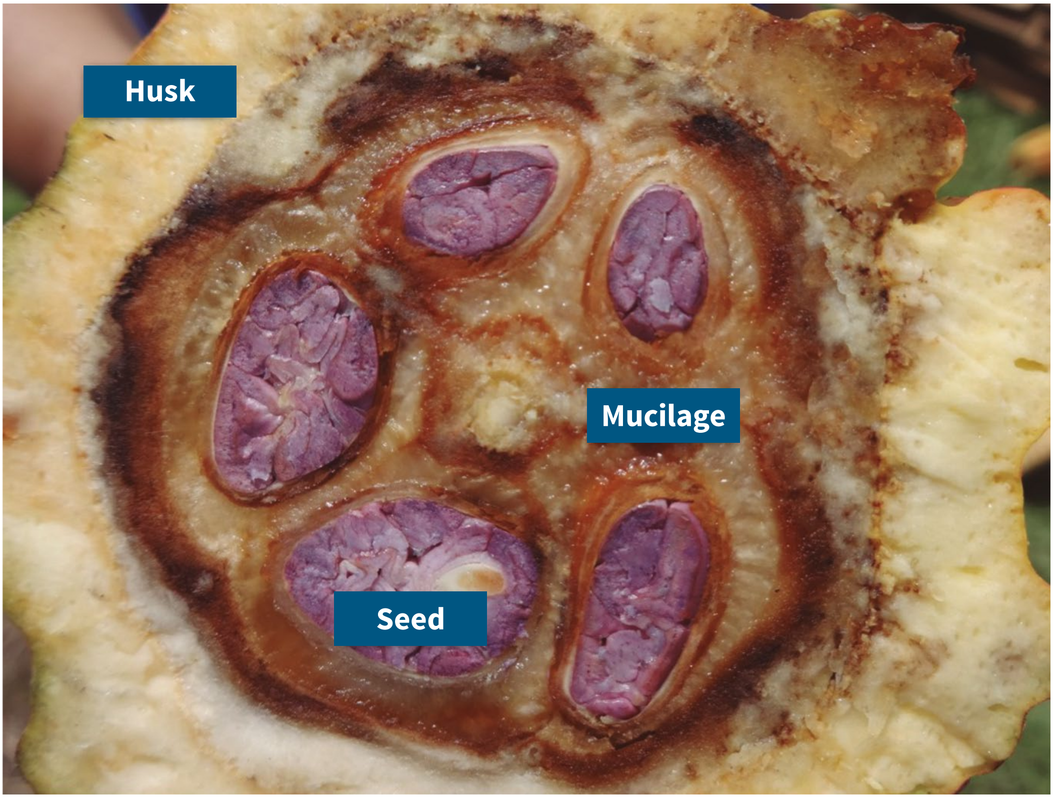
Figure 2.
Cocoa Tree (Theobroma cacao L.)

Source: Authors' owns elaboration.

The cocoa fruit is an indehiscent berry; it does not open or expel its seeds by itself. Instead, the fruit remains attached to the tree by its stalk even after ripening. The husk of the cocoa pod is fibrous, and its thickness is related to the genotype. Inside the pod is a structure with five rows containing the seeds, corresponding to the five locules of the ovary. Its colors range from creamy white to mottled, violet, or purple (as shown in Figure 3, mucilage seeds and husk).

Figure 3.

Spatial Arrangement of Seeds in the Fruit



Source: Authors' own elaboration.

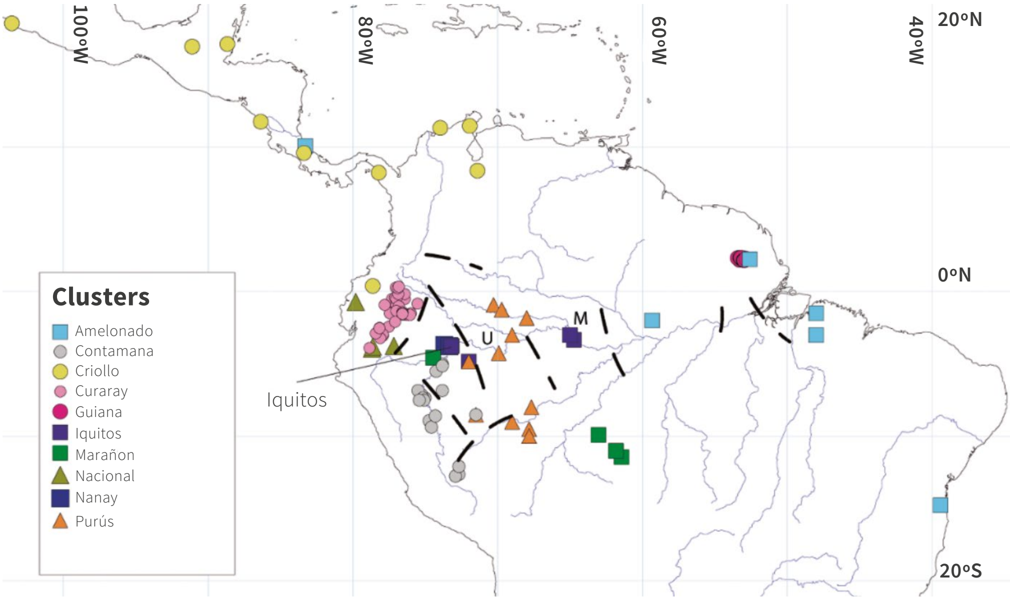
The cocoa seed comprises two cotyledons and the embryo and is covered by a white pulp known as mucilage. Cocoa seeds do not retain their viability after being harvested (Richardson, et al., 2015).

Taxonomically, cocoa is classified into two types according to its genetics: *criollo* and *forastero. Criollo* cocoa was first domesticated and used by pre-Columbian cultures in Central America. It is considered to be fine cocoa with distinguished flavor and aroma. The *forastero* genetic group has numerous wild cocoa populations and varieties found from Guyana and the Orinoco valley to the upper Amazon. The hybridization of these two genetic groups has led to the development of the Trinitario cocoa group, known for its vigor and productivity, which have been adopted within the pure *criollo* populations (Motamayor et al., 2008).

Motamayor et al. (2008) introduced a new genetic classification of cocoa, considering a diversity analysis, which resulted in the molecular characterization of 10 genetic groups: Marañon, Curaray, Criollo, Iquitos, Nanay, Contamana, Amelonado, Purús, Nacional, and Guayana. Below is a map of the locations of the individuals analyzed by the Motamayor team, with genetic groups differentiated by color. It is important to note that these new classifications highlight the vast genetic diversity of cocoa, which can potentially enhance its commercialization based on specific sensory characteristics.

Figure 4.

Location Map of Cocoa Genetic Groups



Source: Motamayor et al. (2008).

Since the 1980s, Colombia has experienced a steady increase in cocoa cultivation, with 175,000 hectares planted. Of these, 31% corresponds to the department of Santander, 9% to Nariño, 8% to Antioquia, and 7.8% to Norte de Santander. Today, 35,000 cocoa-producing families rely on this activity, with many using it as an alternative to illicit crops.

Currently, cocoa is very important for agricultural development in Colombia as it is a source of income, provides job opportunities and projects for the rural population, and contributes to strengthening agriculture and peace-building in post-conflict times (CIAT, 2018).

According to Finagro (2017) and other associations working on improving the quality of Colombian cocoa, it has been classified as a special cocoa with fine flavor and aroma. This designation of specialty cocoa implies compliance with quality standards, such as crop origin, which influence the price increase of cocoa beans or cocoa liquor in national and international markets (Osorio-Guarín et al., 2017).

To achieve recognition of specialty cocoa, it is important to standardize the harvest and post-harvest processes, mainly in the latter activity, where biochemical transformations into aroma and flavor precursors occurs. To determine these organoleptic properties of cocoa, sensory evaluation becomes relevant, which involves establishing laboratories and providing ongoing training for judges in this area (Santander, 2019).

Determining cocoa properties ranges from describing the genetic materials of Colombian cocoa and special features of crops in each cocoa-growing regions of Colombia, to measuring physical, chemical, and sensory parameters of the cocoa bean and cocoa liquor in a sensory laboratory. All of this is framed within the adherence to current national and international technical standards (Djikeng et al., 2018).

Finally, increasing the production of specialty cocoa depends on collaborating with producers and cocoa sector associations to apply good production practices per ton per hectare and, mainly, to monitor the quality of specialty cocoa. This will positively impact the improvement of the family economy for thousands of people engaged in this activity in the country (Moji- ca-Pimiento and Paredes-Vega, 2006).

In Colombia, under the "National Cocoa Production Development Plan 2012-2021," several issues have been identified, including: low quality of dry cocoa beans, limited technological development, lack of knowledge about quality parameters, ignorance of international quality requirements, and issues with association.

To address this scenario, a series of opportunities have been identified, namely: the geographical location within the latitudinal strip, the projection of 726,000 hectares suitable for production, the recognition of Colombian cocoa as fine and aromatic, the progressive increase in domestic and international demand, the implementation of technologies to boost productivity by up to 300%, and the awareness that quality is key to improving the cocoa production chain. In addition, the "Plan de Negocios del Sector de Chocolates, Confites, Chicles y sus Materias Primas" (Business Plan for the Chocolate, Confectionery, Chewing Gums, and Raw Materials Sector) was developed, outlining productivity increases with an expansion in planted hectares to boost domestic production and achieve greater international market impact. In detail, the business plan projects an increase in productivity indicators in the short, medium, and long term, between 2015 and 2032, from 421 kg/Ha to 893 kg/Ha, from 165,000 to 262,000 hectares in use, from 55,000 tons of dry cocoa beans to 222,000 tons, and from 13,700 tons of dry cocoa beans exported to 74,000 tons exported (Fedecacao, 2020).

Accordingly, the development of these plans provides a great opportunity for producers to join forces, improve the productivity of their plots and thus obtain greater resources for their rural business development. The set goals are feasible due to the sustained increase in domestic production, with data showing a rise from 42,279 tons in 2010 to 64,281 tons by October 2020 (Programa de Transformación Productiva, 2017).

In addition, achieving these goals is expected to impact the cocoa supply chain by increasing the number of farming families, the number of processors, the number of people interested in renewing and modernizing their crops, improving phytosanitary quality, optimizing processing systems, and ensuring the final quality of cocoa beans.

Therefore, it is important to highlight the impulse given by the National Government towards achieving the set goals for the benefit of the cocoa production chain actors. This effort aims to firmly establish Colombian cocoa as a fine and aromatic variety globally, which, in turn, is expected to be reflected in improved living conditions for the producers.

In summary, this first chapter provides an overview of the current situation of the Colombian cocoa sector, identifying the challenges, projections and opportunities offered by the different varieties of Colombian cocoa to producers and national processors or exporters. In addition, this sector presents a promising future for both rural and urban areas, offering options for crop diversification, job creation, and social development. This progress is facilitated through the involvement and contributions of chain actors and academia, in their role of transferring knowledge acquired in the classroom and research projects to producers, technicians, processors, marketers, and consumers.

It is important to highlight the impulse given by the National Government towards achieving the set goals for the benefit of the cocoa production chain actors. This effort aims to firmly establish Colombian cocoa as a fine and aromatic variety globally, which, in turn, is expected to be reflected in improved living conditions for the producers.

CHAPTER 2

COCOA QUALITY

This chapter aims to train those involved in the cocoa production chain who, at a given moment, assess the final quality of the cocoa liquor . Readers and those interested in the topic are expected to become advocates of this culture of quality, and acquire fundamental pedagogical concepts and tools. This will enable producers on their farms, buyers and processors to have the theoretical and practical elements needed to determine the fundamentals of the quality of the "fine-flavor and aromatic" cocoa produced in Colombia.

First, it is important to understand that quality is the degree of acceptance or satisfaction a product generates for its user (Icontec, 2015). Therefore, adhering to standardized protocols for cocoa harvest and post-harvest processes is crucial to produce a final product with the physical, chemical, and sensory attributes demanded by markets and processors of fine-flavor and aromatic cocoa. In addition, compliance with technical standards and good agricultural practices is required to offer a product with sensory characteristics that meet market acceptance, thereby establishing a consistent demand for the cacao beans or cacao liquor (Milone, 2018).

The importance of these aspects is paramount in the value chain and includes social, environmental, and economic factors, and special characteristics of cocoa, which guarantee the quality of the final product (Rivera et al., 2012).

Therefore, cocoa quality results from integrating production methods, effective harvest management, and post-harvest treatment, including fermentation, drying, and storage. All these actions aim to enhance the genetic materials of cocoa in terms of flavor, aroma, production, and availability according to market demand (Icontec, 2015).

2.1 PHYSICAL ATTRIBUTES

Most cocoa producers worldwide are owners of small farms or lands. In Colombia, these farms range from 1 to 20 hectares dedicated to cocoa cultivation. The financial sustainability of many families largely depends on the quality of the beans they produce and the establishment of protocols that standardize harvest and post-harvest processes.

However, attributes related to the cultivated genetic material, cultivation practices, and variable control lead to certain physical and sensory characteristics after harvest, classifying cocoa into "fine-flavor and aroma" and "ordinary" categories. There is also the "genotype" variety of cocoa, which has potentially distinctive flavor characteristics, but the maintenance of the crop during harvest and the proper post-harvest processes determines the quality of the final bean (Centre, 2001).

Globally, 95% of cocoa crops are common cocoa, while only 5% are fine-flavor and aroma cocoa. These latter materials are the ones grown in Colombia. Cocoa that is not fine in flavor and aroma is classified as “cacao corriente” (ordinary cocoa) because it is marketed in large volumes of dry beans, and is characterized by its basic cocoa flavor, lacking special aromas or flavors.

The cocoa industry is experiencing commercial growth due to the high demand for this product, related to the volume of production, which is measured in thousands of tons per year. Moreover, there is an economic importance attributed to the premiums paid for cocoa with special attributes. Fine cocoa beans are produced from hybrids of *Criollo* and *Trinitario* cocoa trees, while ordinary cocoa beans come from Forastero cocoa trees (International Cocoa Organization, 2010).

Currently, the most common classification of cocoa genotypes is based on three *Theobroma* cacao materials: 1. Forastero, considered as low-quality bulk cocoa; 2. *Criollo*, classified as fine and flavored cocoa, and 3. *Trinitario,* a hybrid between Forastero and *Criollo*, which can be considered fine in flavor and aroma.

Four factors are considered crucial in achieving a certain degree of quality: the agroforestry system where the crop is grown, the agroecological practices, cocoa genetics manifesting in a large number of varieties, and genotypes, each with its unique characteristics.

Cocoa quality involves good agricultural practices and knowledge of the following stages: cocoa processing, which includes fermentation and drying phases, followed by storage, roasting, nib processing, conching, refining and tempering, and finally, packaging of the final product or chocolate, chocolate bars, cosmetics, and confections (Rektorisova and Tomaniova, 2018).

In addition, crop genetics influences cocoa quality by determining the number of fruits per tree, the number of seeds per fruit, and the bean index. This, along with agroecological crop management and good post-harvest practices, including fermentation, drying, roasting, and storage processes, is crucial (Fedecacao, 2009). Figure 5: Post-harvest Process shows the fermentation and drying process. In the image labeled A, cocoa mass ready for fermentation is placed in a wooden box, and in the image labeled B, cocoa beans are being dried after fermentation through direct exposure to sunlight.

Figure 5.

Post-harvest Process

Source: Authors' own elaboration.

It is important to understand that achieving an adequate quality of cocoa cannot be realized without considering the genetics, the agroforestry management provided by the producer, and the forest system. These elements are essential for ensuring that cocoa production is sustainable and appropriate, thereby guaranteeing the final quality of cacao beans (Sukha et al., 2008).

In the context of cocoa quality, there is also the demand from consumers, who identify specific attributes of cocoa grown in a region. They require that each purchase of the product maintains a consistent sensory profile—regardless of environmental, climatic, or even social conditions. This profile includes the organoleptic and food safety properties.

2.2 CHEMICAL ATTRIBUTES

Cocoa contains different chemical compounds that add flavor and aroma, as well as substances of interest to health and the pharmaceutical industry, including:

- **Methylxanthines.** These alkaloids, particularly theobromine and caffeine, are known for their stimulating effects on the central nervous system. According to various studies, theobromine and caffeine in fat-free beans are estimated to be 4% and 0.2% of dry weight, respectively (Barišić et al., 2019).

- **Sugar aldehydes.** Formed during fermentation and drying inside the bean, these aldehydes are responsible for developing flavor. Three important aldehydes in chocolate due to their aroma are 2-methylpropanal, 2-methylbutanal, and 3-methylbutanal (Santander, 2019).

- **Esters.** Present in both unfermented and roasted beans, esters can also form during fermentation. For example, ethyl acetate is a product of esterification from ethanol and acetic acid. Other esters present during the production of cocoa liquor include isobutyl acetate, isoamyl acetate, phenylethyl acetate, methyl isopentanoate, and methyl isovalerate. Most esters are produced during the aerobic phase of fermentation (Ramos, 2013).

- **Aldehydes.** They give the aroma or bouquet to fruits and flowers. Aldehydes such as 2-methylbutanal and 2-methypropanal are produced during fermentation through the degradation of amino acids.

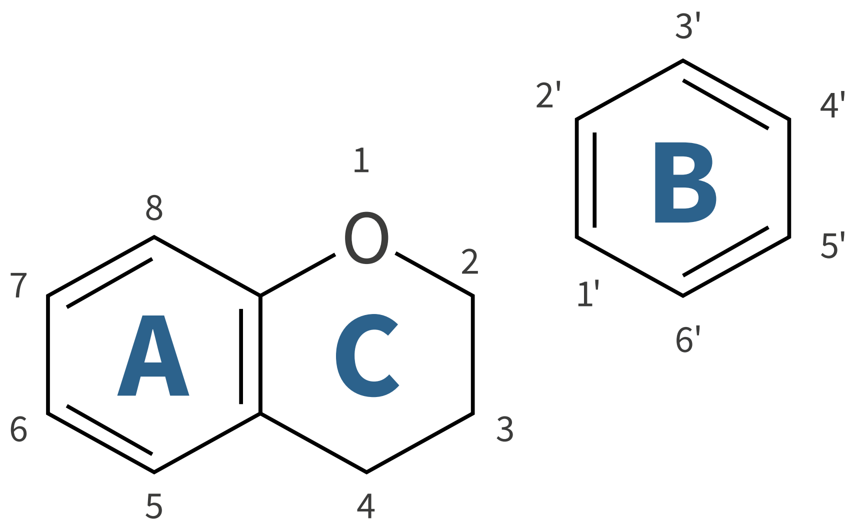
- **Vitamins.** Cocoa fruit and cocoa liquor contain vitamin E, vitamin C, β-carotenes and, naturally, polyphenols. These compounds are of interest to the food and pharmaceutical industries globally (Li, 2014).

- **Polyphenols.** These compounds are important for preserving the health of the cocoa plant and are also included in antioxidants beneficial to human health. Among polyphenols, flavonoids are the most significant group, with over 5,000 identified molecules featuring three rings: two aromatic rings (rings A and B) and a central oxygenated heterocycle (ring C), as shown in Figure 6. These molecules are classified into subgroups such as flavonoids, flavones, flavanones, isoflavones, anthocyanins, and catechins. It is also noteworthy that Criollo cocoa exhibits lower acidity and lower concentrations of polyphenols, resulting in less astringency, particularly in the procyanidin group (Espinosa, 2012).

Another chemical attribute is the acidity in cocoa beans, which is due to the presence of different types of volatile and non-volatile organic acids such as acetic and lactic acid, fermentation products, and mainly citric acid. These substances affect the transformation inside the bean, causing changes in pH values from 6.0-6.5 in unfermented beans to 4.5-5.5 in fermented dry cocoa beans, and influence sensory characteristics, especially the acid attribute. Therefore, this acid content is considered to be of great importance for the final valuation of cocoa (Schwan and Fleet, 2014).

Figure 6.

Biochemistry and Genetics of Cocoa Bean Anthocyanins



Source: Espinosa (2012).

Another significant component is the fat content. Depending on the genetic material, cocoa beans can contain over 50% lipids. Cocoa liquor is known to be the liquid phase generated by the increase in temperature during the grinding of cocoa beans, which contain low melting point fats that are of great importance to the pharmaceutical and food industries, referred to as *cocoa butter*. This material contains lipids for human diets such as oleic, palmitic, and stearic acid. The fats can be separated from the cocoa liquor through mechanical pressing to extract 50% of the *cocoa butter*, leaving a residue known as *cocoa cake*, which is used in confectionery (Tokede et al., 2011).

2.3 SENSORY ATTRIBUTES

It should be noted that during the fermentation, drying, and roasting processes of cocoa beans, molecules responsible for flavor and aroma are produced, resulting from free amino acids, short-chain peptides, and reducing sugars (Frauendorfer and Schieberle, 2008).

Specifically, during roasting, pyrazines are formed through the action of amino acids such as serine and threonine. The amino acids produce volatile heterocyclic molecules that give nutty, roasted, green, and earthy aromas (Mohamadi, 2019).

Higher levels of aromatic precursors in cocoa liquors and chocolates from the *Criollo* variety are attributed to high concentrations of amino acids, peptides, and reducing sugars present in the cocoa beans after fermentation, drying, and roasting.

Based on sensory attributes, the global market classifies tradable cocoa into two major categories: "fine flavor" cocoa and "ordinary, bulk, or regular" cocoa. Fine flavor cocoa, mainly originated from the *Criollo* and *Trinitario* varieties, contains intrinsic and desirable aromas such as “fruity,” “floral,” or “nutty,” which are essential for the production of premium chocolate (Sukha, 2016).

In summary, this chapter exhibits the key aspects of cocoa quality characteristics present in the beans and developed through harvest and post-harvest processes, driven by biochemical transformations that determine the physical, chemical, and sensory attributes expected of cocoa beans according to specific market demands.

The sensory attributes of cocoa genotypes produced in Colombia are established through sensory evaluation panels to create sensory profiles of fine flavor and aroma cocoa. Unions, farmer associations, the national government, and universities conduct regular monitoring of continuous improvement processes in harvest and post-harvest stages (fermentation and drying). They focus on enhancing bean quality and preserving desirable attributes for flavor and aroma. Thanks to these initiatives and the identification of these characteristics in genetic materials from regions such as Santander, Bolivar, Huila, Arauca, and Tumaco, Colombia has achieved recognition as winner at the Salon du Chocolat in Paris.

Based on the context provided, it is expected that in the coming years, Colombian cocoa will achieve quality levels comparable to those of other countries in the region renowned for producing large volumes of fine flavor and aroma cocoa. This goal is projected based on data showing the growing demand from European countries such as Great Britain, the Netherlands, France, and Germany, as well as from major consumers in the United States and Japan (García-Cáceres, 2014).

CHAPTER 3

HARVEST AND POST-HARVEST OF COCOA

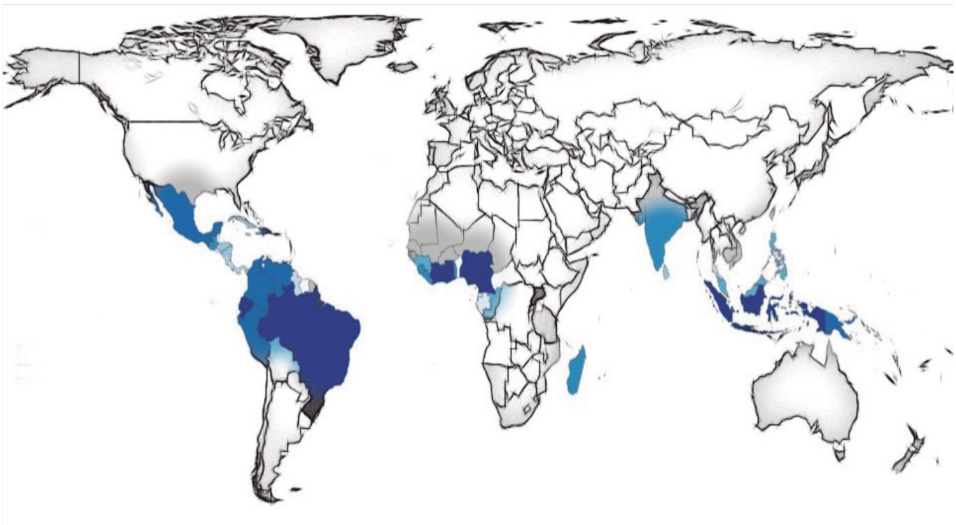
This chapter covers the process that determines the destiny of cocoa beans, their genetics, the agroforestry system where they are grown, recommended agricultural practices, and the effects of the lack of controls during harvest and post-harvest on the final quality of the beans. The following sections review the main stages of these processes, as well as additional stages necessary for producing cocoa liquor, a raw material in transformation processes and key to sensory evaluation and sensory profiling.

3.1 HARVEST

This stage involves learning about the cocoa crop to highlight the quality and, especially, the attributes of fine flavor and aroma cocoa, as defined by the International Cocoa Organization (ICCO).

Cocoa tree is a tropical tree that thrives along the equator around the earth, in the continents of America, Africa, and Asia with latitudes of 20° south and north (Figure 7). In terms of altitude, cocoa cultivation is feasible from zero up to 1,200 meters above sea level, with the best production results at 600 meters.

Figure 7.
Current Distribution of Cocoa Cultivation Worldwide



Source: ICCO (2010).

In Colombia, cocoa production features two main harvest seasons: from April to June and from October to December. In other cocoa-producing countries, harvest seasons vary depending on rainy and dry seasons.

3.1.1 HARVESTING

Harvesting is the task of removing cocoa fruits from the tree. These fruits change color from green to different shades of yellow, and eventually to purple and red, depending on the different cultivated phenotypes. During this stage, the fruit reaches its maximum growth size, which, along with color, indicates a "ripe fruit" appearance as shown in Figure 8. Harvesting fruits that are not fully mature will negatively affect the final product's sensory characteristics, as unripe beans produce a bitter taste and the mucilage covering the bean will lack adequate sugar concentration. Consequently, this will compromise the optimal conditions for fermentation and other biochemical processes inside the cacao bean, which are essential for transforming into new aroma and flavor precursor molecules (Colombian Technical Standard [NTC] 5811, 2010).

Figure 8.
Harvested and Collected Fruits

Source: Authors' own elaboration.

For fruit harvesting, it is important to use the appropriate cutting tools. The pedicel of the cocoa fruit should be cut exclusively with pruning shears, as shown in Figure 9. Using general cutting tools such as machetes can injure the tree and damage the floral cushion or affect the beans on the pod. To avoid damage to the floral cushion and trunk, it is advisable to disinfect the shears and avoid pulling the cocoa fruits by hand, as this can affect productivity by damaging the cushion and causing trunk diseases (De Almeida and Valle, 2007).

Figure 9.

Cutting the Pedicel of the Cocoa Fruit

Source: Authors' own elaboration.

3.1.2 SPLITTING THE PODS

After removing the cocoa fruits from the trees, a selection process is carried out to separate healthy fruits from those with lesions caused by fungi, insects, birds, or mammals (as well as green pods or fruits), or those suspected of not having reached the appropriate level of maturity. To ensure adequate final quality, only ripe and healthy fruits should be processed. Splitting the pod with a machete should be done longitudinally, with prior disinfection of the tool as shown in Figure 10. Other cutting instruments, such as a wooden mallet or stainless-steel guillotine, are also used to ensure better aseptic conditions and reduce occupational accidents (Gutiérrez, 2017).

Figure 10.
Splitting the Cocoa Pod or Cocoa Fruit to Extract the Seeds

Source: Authors' own elaboration.

Ideal characteristics of cocoa beans within the fruit or pod include being free of damage and having sufficient ripeness. This activity is recommended to be carried out outside the plantation. Figure 11 shows a longitudinal split of the cocoa pod or fruit, with ideal aseptic conditions and no damage to the beans or mucilage.

Figure 11.
Longitudinal Arrangement of Cocoa Beans Covered by Mucilage in the Pod

Source: Authors' own elaboration.

3.1.3 SHELLING

The process of separating the beans from the shell is known as shelling. This involves a mechanical action of sliding fingers or a tool along the longitudinal axis of the pod. This activity requires disinfection of all tools and the use of gloves or meticulous hand washing to avoid cross-contamination, which could affect the product's quality and put the health of consumers at risk (Santander, 2019).

Figure 12.
Shelling or Extracting Cocoa Beans with Mucilage

Source: Authors' own elaboration..

3.2 POST-HARVEST

This process involves the conversion of molecules such as proteins and sugars into simpler ones, which reduce the bitterness and astringency while releasing new flavor and aroma attributes known as "notes." The notes are typical of various genetic materials but can also arise from good agricultural and food handling practices.

Cocoa processing or fermentation refers to the biochemical transformations that occur inside the cacao bean. After being removed from the fruit and placed into various types of special containers, ranging from baskets to wooden crates (rectangular, cubic, or cylindrical), under appropriate conditions (covered structures with mesh walls and roofs), the beans undergo physical and chemical transformations. These changes are caused by fermentation by-products that enter the cocoa bean, enhancing its sensory characteristics (De Vuyst and Weckx, 2016).

According to the 2018 Fedecacao report, 38.5% of Colombian producers lack infrastructure for cocoa processing, whereas the remaining 61.5% do have it. Of this latter percentage, 94.6% use wooden crates and 5.4% use barrels for fermentation. This situation significantly impacts the standardization of the fermentation process; and promoting association is recommended to create centralized processing systems for controlled quantities.

Cocoa processing is fundamental for quality because it develops the precursors for flavor and aroma and results in beans with a desirable appearance and kidney-like structure in shades ranging from cream to brown. Adequate fermentation produces cocoa beans that, when transformed into chocolate, are sensorially pleasant in terms of flavor and aroma. Inadequate fermentation will yield low-quality cocoa (Biehl et al., 1982).

During fermentation, water adsorption occurs, increasing the bean volume by 17% to 27% within 40 hours. The bean's cellular structures are destroyed by water and temperatures above 50°C. Water adsorption is then reduced due to the presence of osmotic substances such as sucrose. Embryo death is caused by high temperatures and acetic acid (200 mmol; pH 2.7).

An important recommendation is to avoid mixing beans from different harvest days. Each cocoa batch should undergo independent processing, as mixing cocoa from different harvests can result in beans with different fermentation indices, altering quality and desired organoleptic properties. It is advisable to schedule pods harvests that allow for independent fermentations and have enough fermenters for large and small volumes (Magee et al., 2017). Figure 13 illustrates the distribution of mass in the fermentation crate.

During fermentation, chemical reactions occur with the carbohydrates in the mucilage, generating water, ethanol, and acetic acid. Fermentation begins with an anaerobic phase, followed by metabolic processes created by yeasts, which produce alcoholic fermentation and heat. In the second phase, fermentation is aerobic. This phase involves a group of microorganisms that transform the products generated by yeasts and develop other processes such as polyphenol oxidation and important pH changes, mainly due to acetic acid production. It is important to note that the fermentation period varies from 5 to 7 days (120 to 168 hours), depending on cocoa genotype, cocoa bean index, and environmental conditions (Warren, 2020).

Figure 13.

Cocoa Fermentation in a Wooden Crate

Source: Authors' own elaboration.

3.2.1 DRYING

To store cocoa beans without damage from fungi or other pathogens, the water content inside the beans must be around 7% moisture. Biochemical processes do not end after fermentation. During drying, additional biochemical reactions occur that facilitate the transformation, acetic acid removal, formation of flavor precursors, oxidation and conversion of polyphenols, browning, and the kidney-like shape of the beans, resulting in the expected sensory characteristics (De Vuyst and Weckx, 2016).

For sun drying, tray systems, *Casa Elba* (it is a rooftop structure for drying), wooden tables, or Elba-type sliding systems are used. Drying should not be done on concrete floors or paved areas to prevent contamination from animals or undesirable substances.

During the drying process, frequent movement is necessary to ensure the removal of cocoa mass and achieve the evaporation of moisture and volatile acids through the homogeneous distribution of heat and thus achieve uniform drying. Wooden tools are recommended over metal tools to prevent damage to the beans' appearance (Tinoco and Ospina, 2010). Figure 14 shows a greenhouse-type dryer that allows adequate management of exposure periods.

Figure 14.

Convective Drying in a Greenhouse-Type Structure

Source: Authors' own elaboration.

During the cleaning stage, impurities, moldy beans, broken beans, or flattened beans are removed. The Colombian Technical Standard (NTC in Spanish) 1252 of 2021 outlines the minimum requirements for cocoa beans to be marketed (Moreno, 2019).

According to the Fedecacao report, in 2018, 96 % of Colombian producers performed sun drying, 0.47 % used artificial drying, and 3.84 % sold cocoa mucilage to collection centers. Within the 96 % of sun drying, the following systems stand out in order of importance: Elba 38.38 %, plastic 30.66 %, cement patio 15.93 %, marquee 9.96 %, raisin 3.20 %, stretcher 1.04 % and others 0.8 %. This wide variety of systems affects drying dynamics in terms of temperature, relative humidity, time, thickness of cocoa layers, and contamination risk, ultimately impacting the quality of the dried cocoa beans (Fedecacao, 2017).

3.2.2 STORAGE

Storing dried cocoa beans requires a well-ventilated facility that allows for visual inspection, easy rotation of stored products, and conditions of humidity, cleanliness, and pest control that can be verified. According to the Food and Agriculture Organization (FAO), cocoa beans should contain no more than 7% moisture to be preserved for long periods in storage (Medina and Vargas, 2009).

The product must be packed in burlap or jute bags with twine thread or fique fibers, as established by NTC 5517 of 2007. Each cocoa sack has a net weight of 60 kilograms. These sacks should be stored on wooden or plastic pallets, arranged in stacks depending on the warehouse dimensions, product rotation, and good handling practices required by food products. Figure 15 shows proper storage of dried cocoa beans.

Figure 15.
Storage of Dried Cocoa Beans

Source: Authors' own elaboration.

3.2.3 ROASTING

Roasting occurs when cocoa beans are destined for the production of table chocolate or other chocolate products. Roasting, or torrefaction, is a crucial thermal process that generates reactions such as the Maillard reaction, whose flavor and aroma precursors are molecules of reducing sugars and amino acids developed during fermentation. Volatile compounds are produced due to increased temperatures, which can range from 90°C to 115°C, for durations of 15 to 40 minutes in rotary ovens, depending on the volume of cocoa to be roasted and laboratory conditions.

Time and temperature are the two main variables to be considered in roasting, together with the increase in pyrazine concentration. Pyrazines, identified by different authors as precursors of cocoa or nutty notes, include: 2,3-dimethylpyrazine, trimethylpyrazine, tetramethylpyrazine, 3 (or 2), 5-dimethyl-2 (or 3)-ethylpyrazine, and 3,5 (or 6)-diethyl-2-methylpyrazine. In addition, three Strecker aldehydes have a strong chocolate flavor: 2-ethylpropanal, 2-methylbutanal, and 3-methylbutanal. Strecker degradation is a reaction of the dicarbonyl compounds of the Maillard reaction and reacts with the α -amino group of an amino acid to form a Schiff base (aldehyde or ketone-type compounds where the carbonyl group is replaced by an imine or azomethine group).

Aldehydes formed through Strecker degradation are essential in flavor production in foods (Marseglia et al., 2020).

In laboratory rotary ovens (Figure 16), tests can be conducted with sample sizes starting from 500 grams, with control over temperature and time variables. It is important that these variables are adjusted according to the type of cocoa and the quantity used.

Figure 16.
Rotary Oven for Cocoa Roasting

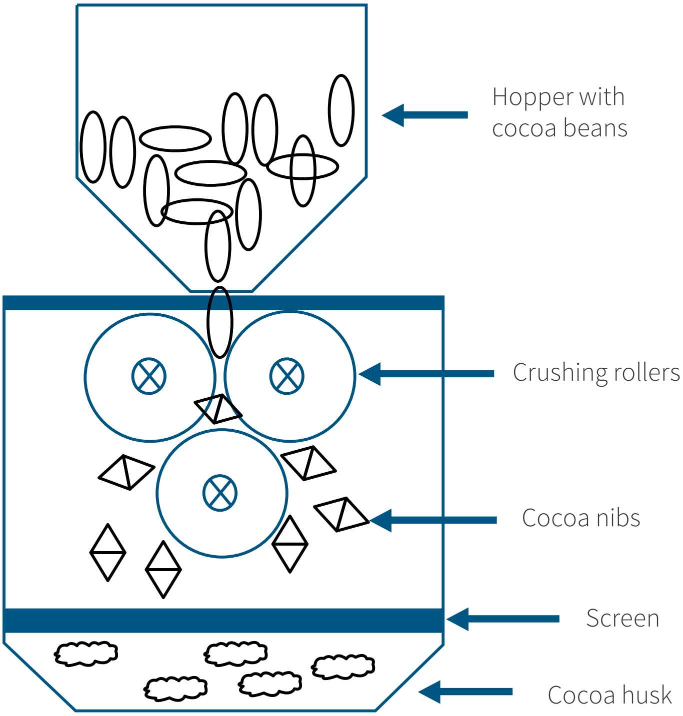
Source: Authors' own elaboration.

3.2.4 HULLING

After drying, the processing of cocoa beans involves hulling, a physical process with various methods available. One of the most recommended practices in both industry and laboratory settings is to first roast the beans, and then, once they have cooled to room temperature, proceed with hulling.

The hulling machine is equipped with a hopper or tank at the top, allowing gravity to initiate the feeding of the equipment. Generally, hullers are equipped with a vibrating screen to remove some of the debris of the beans. Once the cocoa beans are introduced, they pass through three rubber or steel rollers that break them apart. This fragmentation releases pieces of cocoa husk along with cocoa nibs (cocoa cotyledon particles). A second vibrating screen then completely separates these two types of particles: the lighter and finer husk passes through the screen, while the nibs remain in the center, as shown in Figure 17.

Figure 17.
Diagram of a Hulling Machine



Source: Authors' own elaboration.

Other methods include using a fan that blows low-pressure air to remove the lighter shell debris, which are then directed to another tank. Removing the husk is important to prevent impurities in the cocoa liquor and the final texture of the products from being affected. It is recommended to maintain control over this process to avoid such defects.

3.2.5 GRINDING AND REFINING

Cocoa nibs are the starting point for grinding, a process achieved through mechanical action using either a granite roller system known as a "melangeur" or steel ball mills, which ensure uniform conditions across production batches. Figure 18 illustrates the stone system of a stone or granite roller refining machine.

Figure 18.
Graphite Stones used for Grinding Cocoa Nibs

Source: Authors' own elaboration.

3.2.6 COCOA LIQUOR PREPARATION

Cocoa beans are processed to produce "cocoa liquor," a liquid compound formed after grinding the cocoa nibs, which have previously undergone fermentation, drying, and roasting processes.

The term "liquor" refers to the liquid phase of cocoa resulting from the mechanical action of grinding until achieving a particle size of 17 μm (micrometer). The palate detects a gritty texture with liquors of 25-35 μm. Most commercial fine chocolates are considered to have a particle size of 5 μm (Breen et al., 2019). Figure 19 shows the grinding of cocoa nibs and the formation of cocoa liquor.

Figure 19.

Grinding of Cocoa Nibs and Formation of Cocoa Liquor

Source: Authors' own elaboration.

Cocoa liquor is stored in small molds for chocolate bar production or in larger molds to have a wide variety of cocoa liquor flavors available for a sensory evaluation panel or other uses (see Figure 20). These samples require refrigeration at 4°C and storage time can range from one to two months. The refrigerator must be exclusively used for storing cocoa liquor to avoid contamination from odors of other substances, which could alter the organoleptic properties of the product.

Figure 20.
Molding Cocoa Liquor for Storage

Source: Authors' own elaboration..

Solidified cocoa liquors are stored for several months. Although the fat in the cocoa liquor may move to the surface, giving it a whitish appearance, this phenomenon does not affect the flavor. The production of cocoa liquor does not require tempering, as this is a key stage in chocolate production (a topic for future publications).

Cocoa liquor is a raw material for various food products in the chocolate and confectionery industries, hence the importance of cleanliness during storage. Besides cocoa liquor, there are other industrially significant products such as cocoa cake, a defatted, agglomerated cocoa paste formed after pressing cocoa liquor. It contains low fat percentages and is mainly used in the ice cream, toppings, and granulated beverage industries, among others. Cocoa powder can also be obtained from this product by pulverizing the cocoa cake.

Another industrially important product is cocoa butter, which constitutes 55% of the cocoa fat. Its characteristic yellow color is obtained from pressing the cocoa liquor, and it has a solid, oily texture. Cocoa butter is a raw material in the pharmaceutical and cosmetic industries and forms the base of white chocolates.

Finally, Figure 21 illustrates the overall process of transforming cocoa beans into cocoa liquor (Frauendorfer and Schieberle, 2008).

Figure 21.

Overall Process of Transforming Cocoa Beans into Cocoa Liquor

Source: Authors' own elaboration.

On the one hand, grinding is a physical-mechanical process that refines cocoa liquor or the liquid phase to particles ranging from 17 to 20 microns (μm) (a micron is one thousandth of a millimeter). In turn, the refining process releases flavor and aroma precursors preserved through good harvest and post-harvest practices. The texture threshold for the palate is approximately 35 μm. A size below 15 μm may result in some cocoa butter being released, giving the chocolate product a greasy texture.

For chocolate production, cocoa liquor must be refined through the conching process, which eliminates undesirable aromas and enhances flavor and aroma precursors. This technique involves mechanical agitation and controls variables such as temperature and time to achieve the desired final aroma, viscosity, and texture of the chocolate (Afoakwa et al., 2008).

In summary, this chapter covers the basic concepts of the physical and biochemical processes involved in the fermentation and drying of cocoa beans, which determine the quality of the cocoa beans and the foundational raw materials for chocolate making.

Fermentation is a critical step, facilitated by the sugars in the cocoa mucilage, which serve as a substrate for microorganisms such as yeasts that perform the catabolic process from sugars to alcohol, along with temperature increases (>50°C) and pH decreases. Under these conditions, the embryo dies and the cotyledon forms new compounds. Monitoring the pH value of the cotyledon becomes a key indicator for tracking the fermentation process, indicating whether fermentation is inadequate with values above 5.5, good between 4.5 and 5.5, and whether the drying process has been insufficient if volatile acids are not removed, affecting the final quality of the cocoa liquor.

Likewise, drying cocoa beans is a delicate activity, especially in terms of drying times and depending on whether it is done under direct sunlight, through convection systems, temperature-controlled systems, or a greenhouse. The most important thing is to maintain a homogeneous drying of the cocoa batch over the required days, depending on the volumes and size of the bean. Accelerating the process can trap substances such as acetic acid inside the bean, giving an unpleasant flavor. Finally, the dried beans are processed in processing plants or food laboratories to convert them into cocoa liquor, which can then be used in chocolate and confectionery products.

Throughout the cocoa supply chain, different procedures aim to maintain the quality of the cocoa and its derived products. This is supported by good agricultural and manufacturing practices, as well as compliance with legislation, standards, and technical guidelines aimed at process standardization, so that cocoa, cocoa liquor, and resulting products are recognized for the attributes desired by consumers and processors.

To achieve the final quality of cocoa, in addition to good practices during the key stages of fermentation and drying, it is crucial that technicians, technical institutions, universities, and research groups become aware of the importance of standardization and the culture of control of such processes. Once producers and processors understand these processes and how to monitor them, they will be able to make informed decisions to ensure the quality of the final product.

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CHAPTER 4

EVALUATION OF THE PHYSICAL QUALITY OF COCOA

This chapter explores the key indicators of physical quality for cocoa beans considered at the point of sale. These indicators not only determine the quality of a batch of cocoa beans but also form the basis for the regulatory standards governing the buying and selling process. In Colombia, this process is standardized by NTC 1252 of 2021, a voluntary standard that is currently adopted as an essential document for regulating the quality of dried cocoa beans. Globally, the ISO 2451 of 2017 is the prevailing standard used.

While NTC 1252 focuses mainly on bean quality, ISO 2451 emphasizes the quality of cocoa bean batches. However, in general terms, the physical quality indicators for the beans are consistent across both standards and share the same objectives. Therefore, users of these standards must have a thorough knowledge of each one, including how they determine each characteristic and the leading indicators, such as moisture percentage, fermentation index, bean index, and husk percentage, as well as the most commonly used methods in our area and analytical developments aimed at improving quality (ISO 2451, 2017).

Tables 1, 2, and 3 outline the characteristics required for evaluating the quality of dried fermented cocoa beans according to NTC 1252 (2021).

Table 1.

Requirements for Cocoa Beans

Physical and chemical requirements	Classification of cocoa beans		
	Premium / Special	Standard	Common
Minimum % of well-fermented beans	70	65	55
Maximum % of insufficiently fermented and purple beans	30	35	45
Mass (weight) of 100 beans (g)	> 120	95 - 120	< 95
Maximum moisture content (%)	7.0	7.5	7.5

Source: NTC 1252 (2021).

Table 2.

Tolerances for Cocoa Beans

Tolerances for cocoa beans			
Maximum % of impurities or foreign matter	0	0.3	0.5
Maximum number of beans with internal mold (per 100 beans)	1	3	5
maximum number of beans damaged by insects or sprouts (per 100 beans)	1	2	3
Maximum number of split beans (per 100 beans)	1	2	5
Minimum % of kernels (fraction by mass)	N/A	N/A	40 - 60
Maximum % of unfermented beans (slaty)	1	3	5

N/A: Not Applicable.

Note: The term "Kernel" refers to the cotyledon or fragment of the cotyledon of the cocoa bean.

Source: NTC 1252 (2021).

Table 3.
Sensory Specifications

External Sensory Characteristics Evaluated at the Time of Reception by On-Site Inspection			
Sensory characteristics	**Unfermented beans**	**Insufficiently fermented beans**	**Fermented beans**
Appearance	Whole beans, free from mucilage residues, mold, insects, or foreign matter.	Clean beans, free from mold, holes, insects, or foreign matter.	Clean, swollen beans, free from mold, holes, insects, or foreign matter.
Texture and consistency	Smooth beans with difficult-to-remove husk, resistant to cutting.	Slightly rough beans, difficult-to-remove husk.	Rough, brittle beans with easy-to-remove husk.
Internal Sensory Characteristics Evaluated in the Cutting Test, at the Time of Reception by On-Site Inspection			
Characteristics	**Unfermented beans**	**Insufficiently fermented beans**	**Fermented beans**
Appearance	Smooth and uniform, free from mold, insects, or fragments.	Partially striped and porous, free from mold, insects, or fragments.	Striped and porous, free from mold, insects, or fragments.
Color	Cream to violet, dark purple.	Partially cream to violet and cream to dark brown.	Cream to dark brown
Texture and conformation	Smooth, cut-resistant interior.	Moderately resistant to cutting, partially rough, and not very fragile.	Granulated, rough, fragile under pressure and cutting.
Flavor	Bitter, slightly acidic, and astringent, free of atypical attributes and flavors.	Cocoa flavor with predominantly acidic, bitter, and astringent flavors. Free of atypical attributes and flavors.	Characteristic cocoa flavor with a balanced profile of basic attributes: acidic, bitter, and astringent. Free of atypical attributes and flavors according to fermentation level.

Odor	Characteristic of unfermented cocoa, free from foreign odors.	Pungent, characteristic of acetic fermentation, free from foreign odors (e.g., earth, smoke, diesel).	Pungent, characteristic of acetic fermentation, free from foreign odors (e.g., earth, smoke, diesel).
Note 1: Foreign matter refers to substances not related to cocoa and has no value to the manufacturer. Examples include twigs, stones, other beans (e.g., common beans, coffee), dust, glass, iron, etc., which cause physical contamination from mishandling of the product. Note 2: See section B.4 for examples of some sensory characteristics of dried cocoa beans.			

Source: NTC 1252 (2021).

Tables 4, 5, and 6 exhibit the dried cocoa bean classification for fermented and unfermented beans, and the physical parameters according to ISO 2451 of 2017.

Table 4.

Internal Classification of the Producing Country for Fermented Beans

Grade	Percentage of beans		
	Moldy	Slaty	Damaged by insects or sprouts
1	3	3	3
2	4	8	6
Note 1: Percentages are maximum values. Note 2: Percentages given in the last column apply to the combined total of all defects specified in the column heading.			

Source: ISO 2451 (2017) and NTC 1252 (2021).

Table 5.

Internal Classification of the Producing Country for Unfermented Beans

Grade	Percentage of beans		
	Moldy	Slaty	Damaged by insects or sprouts
1	3	≥20	3
2	4	≥20	6
Note 1: Percentages are maximum levels. Note 2: Percentages given in the last column apply to the combined total of all defects specified in the column heading.			

Source: ISO 2451 (2017) and NTC 1252 (2021).

Table 6.

International Trade Classification for Fermented Beans

Grade	Bean content %	
	Slaty	Moldy or damaged by insects
Well fermented	5	5
Regularly fermented	10	10

Note 1: Percentages are maximum levels.
Note 2: Percentages given in the last column apply to the combined total of all defects specified in the column heading.

Source: ISO 2451 (2017) and NTC 1252 (2021).

This standard establishes that when a cocoa bean has severe defects, it must be classified into a single category, typically the least favorable one. The severity of defects is ranked in decreasing order as follows:

- Moldy beans
- Slaty beans
- Insect-damaged beans
- Sprouted beans (not applicable to Table 3).

Regarding Colombian cocoa bean size, Fedecacao (2016), in its Guia Técnica (Technical Guide in English), classifies beans with a high index as >1.7 g, medium as 1.4-<1.7 g, and low as < 1.4 g (Fedecacao, 2016).

4.1 MOISTURE CONTENT

According to NTC 1252 and ISO 2451, a batch of Colombian cocoa for export is expected to have a moisture content between 7% and 7.5%. This parameter is crucial for preserving the dried cocoa beans and preventing the proliferation of microorganisms, especially mold (Fedecacao, 2013).

To achieve this, the loss of bean moisture up to 7% must be gradual and uniform, i.e., rotating the total mass harvested to ensure that all cocoa beans are exposed to the same environmental conditions of the site intended for drying (sunlight or facilities that allow heat convection) (Moreno, 2019). Figure 22 shows the cocoa beans during the drying process, a critical stage that defines the physical aspects of specialty cocoa.

Figure 22.

Cocoa Beans in the Drying Process

Source: Authors' own elaboration.

Moisture content is determined by measuring a physical variable that indicates the amount of water dissolved in a gas or, in the case of cocoa, the water absorbed by a solid. Proper drying ensures that the beans retain the characteristic flavors and aromas of cocoa during storage. It also ensures the safety of the final product, as high moisture content can lead to fungal, bacterial, and insect infestation. Cocoa beans have a moisture content close to 60% immediately after fermentation, and it is essential to reduce this to 7% during drying to preserve the beans for storage.

To guarantee the quality of the beans in terms of preferred flavors and aroma, drying protocols must establish exposure times to sunlight or convection heat sources in automated systems. Likewise, the homogeneity of drying for the entire batch of fermented cocoa must be monitored with scheduled turnings to ensure consistency (Ndukwu et al., 2011).

Moisture content is measured in a representative sample of cocoa taken randomly from the batch. In the field procedure a moisture meter is used, which can be specific for cocoa or with an equipment used to measure moisture in beans that has in its specifications the option for cocoa beans. It is important to set up the equipment and handle the sample with gloves. The latter to avoid mistakes, because if the hands are wet, moisture can be transmitted to the beans.

The moisture meter consists of a small chamber where cocoa beans are stored until the space is filled. Bottle-type devices are set to perform three tests and calculate an average moisture percentage. To ensure accurate readings, the chamber is covered when filled to the rim. Then, the lid, which has a recessed button in the center, is screwed on. As it is screwed on, the button must be level with the top of the lid to ensure proper use. The button referred to is shown in Figure 23.

Figure 23.
Moisture Detector for Cocoa Beans

Source: Authors' own elaboration.

It is recommended that these devices be verified against laboratory methods for moisture testing. This involves using a muffle furnace at 105°C. A quantity of 5 grams of ground cocoa beans is placed in the muffle furnace and subjected to this temperature for four hours. The beans are then weighed on an analytical scale until a constant weight is achieved to determine the moisture percentage.

This moisture content is key to processors because if it exceeds 7.5 %, it translates into losses during processing. The higher the moisture percentage, the greater the loss for the processor. Therefore, it is essential to keep the drying and storage processes under control to avoid increasing moisture in the beans and, additionally, to prevent mold growth both on the outside and inside of the beans.

4.2 BEAN INDEX

In the cocoa sector, several characteristics are sought in crops to provide competitive advantages to producers through the management of planting models that improve seven quality factors: productivity, high intercompatibility, self-compatibility (self-fertilization between pollen and ovules of contiguous trees or those of each tree), disease resistance, tree size, special flavor, and bean size (Fedecacao, 2016).

The bean size factor is intended to increase processing yields for greater utilization. For chocolate and cocoa butter production, NTC 1252 establishes the bean index parameter for cocoa, which determines the average weight of beans in grams. This involves using 300 cocoa beans with their husks and unroasted, weighing each bean individually on an analytical scale while avoiding air currents, and then summing the values which are then divided. It is important to conduct this activity in a laboratory or other area where there is no foot traffic or other interactions to avoid distractions (see Figure 24).

Figure 24.
Laboratory Conditions for Bean Index Measurement

Source: Authors' own elaboration.

According to Fedecacao (2016), the Colombian bean index will be: high >1.7 g, medium 1.4-<1.7 g, and low <1.4 g.

ISO 2451 of 2017 uses the count of beans per 100 grams as an indirect measure of bean size but is designed specifically for cocoa beans obtained from African suppliers, whose beans are typically smaller.

The bean index studied as a productivity factor is a reference for higher plant yields. This index is critical in the processes of extracting cocoa butter and roasted and ground beans, as expected by buyers. Therefore, it is critically important for the scientific community to seek cocoa genotypes that produce well-sized beans.

4.3 HUSK PERCENTAGE

The husk percentage is a crucial indicator for processors as it directly impacts the yield of the selected cocoa during processing. Generally, varieties with a good bean index and low husk percentage are sought after.

The husk of cocoa beans is a by-product in the transformation into cocoa liquors and chocolate. It is removed from the cocoa bean during the thermal roasting process. The husk encloses the cotyledon and adheres to the mucilage on the outer surface. Depending on the genetic materials, the husk can account for 12 % to 14 % of the total bean weight.

The husk has a significant number of substances considered beneficial to human health. Among them are polyphenols, reported in concentrations of 1-2 %, alkaloids such as theobromine (1-2 %), vitamin D, minerals (calcium and phosphorus), amino acids, and soluble and insoluble dietary fibers (25-30 %) (Hernández-Hernández, 2019).

The husk percentage can be determined by analyzing 50 randomly selected beans in triplicate. The husk is removed and weighed for each bean. The same process applies to the naked beans that are converted into cocoa nibs or small fragments formed by the grooves and present during fermentation, as shown in Figure 25. This process is performed in triplicate to generate an average husk percentage (Vera et al., 2015).

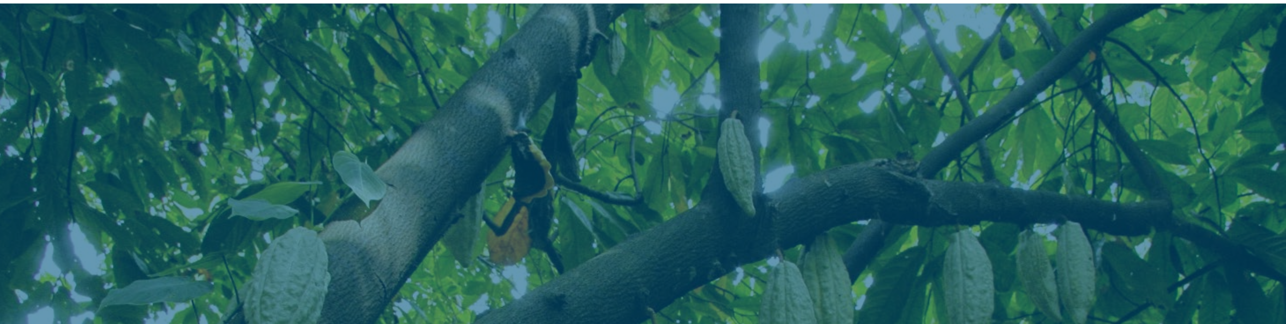


Figure 25.
Husk on the Left Glass and Cocoa Nibs on the Right One

Source: Authors' own elaboration.

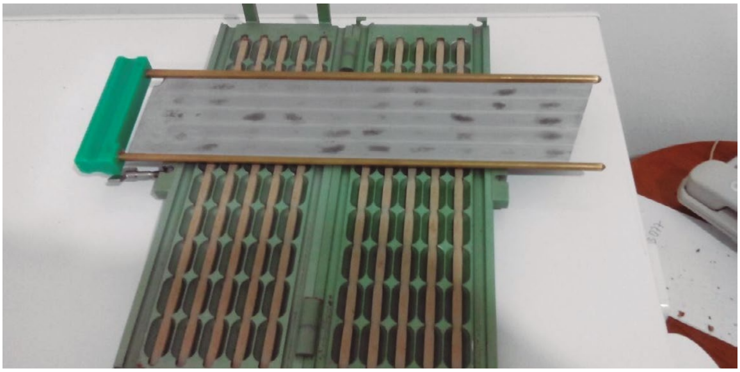
4.4 FERMENTATION INDEX

The fermentation rate is an indicator of the efficiency of the fermentation process. This analysis helps establish the destination of the cocoa bean and project the final quality of the cocoa liquor obtained from the cocoa bean. In addition, this analysis also checks the health of the cocoa bean. It is a sensory test that must be conducted by trained and experienced personnel, as factors such as the testing site (properly lit), the equipment used for cutting the beans, and the number of beans analyzed can influence the results.

It is important to note that this analysis determines the fermentation percentage and the presence of defective beans that influence the final quality of the cocoa according to Colombian technical standards and global cocoa quality analysis protocols (Leite, 2013).

When performing this test, it is crucial to ensure that the beans are no more than 30 days dried, as longer periods can affect the final results due to oxidation of the cocoa beans. The methodology involves taking 300 cocoa almonds, placing them on a guillotine in batches of 50 for cutting (see Figure 26), and then conducting a longitudinal cut of the cocoa beans to determine the number of beans that are well-fermented, partially fermented, and unfermented.

Figure 26.
Guillotine for Cutting Cocoa Beans



Source: Authors' own elaboration.

The use of a guillotine allows for the identification of the sanitary quality of cocoa beans that show damage from insects or fungi, as illustrated in Figure 27:

Figure 27.
Longitudinal Cut of the Cocoa Bean Using Guillotine

Source: Authors' own elaboration.

Once the bean is cut, it is visually analyzed. Adequate environmental and lighting conditions must be ensured to verify:

- Overly swollen brown beans: Beans with swollen and kidney-shaped cotyledons.
- Partially brown and purple beans: Characterized by partial swelling and semi-compact cotyledons, indicating partial fermentation.
- Totally purple beans: This coloration is caused by a lack of fermentation.
- Slaty and gray beans: With very compact cotyledons that affect the quality of the cocoa liquor.
- Infected beans: Presence of insects. Cocoa bean infection can be prevented through proper drying practices.
- Germinated beans: These promote the entry of fungi and pests.
- Flattened beans (*pasilla*): Resulting from harvesting immature pods and mixing their beans with mature ones (Quintana F. et al., 2018) FTA2 and FSA12.
- Moldy beans: Mold present inside the cotyledon. This occurs during drying or storage of the bean when its moisture content exceeds 7%. Some common molds such as Aspergillus and Penicillium produce mycotoxins that degrade the substrate and are associated with liver cancer. After mold colonization on the cocoa bean surface, it is best to discard that batch or harvest as a food product for human consumption (see Figure 28).

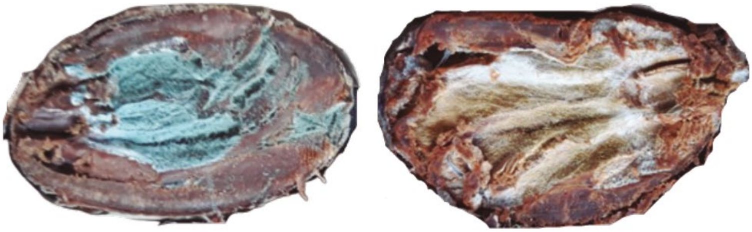
Figure 28.

Cocoa Bean Infection with External Mold

Source: Authors' own elaboration.

Fungi can also colonize the inside of cocoa beans and cause total damage, as they not only produce toxic substances but also generate unpleasant odors and flavors. Figure 29 shows molds in sporulation on the right and cottony molds on the left.

Figure 29.
Mold Colonization Inside Cocoa Beans



Source: Authors' own elaboration.

The toxigenic mold species described above in cocoa beans belong to the species or groups of species: *Aspergillus flavus, Aspergillus parasiticus, Aspergillus nomius, Aspergillus niger group, Aspergillus carbonarius, Aspergillus ochraceus,* and *Penicillium paneum.* As previously mentioned, the highest percentage of toxigenic molds is acquired during drying and storage (Copetti, 2011).

All fungi belong to the kingdom Fungi, a highly varied group in forms and sizes, characterized by decomposing organic matter into simpler compounds used by living organisms. According to the specialization in different substrates, some fungi have a group of powerful enzymes capable of degrading organic and inorganic compounds. When consumed by humans, they often cause chronic diseases, hallucinations, and even death. Fungi are considered opportunistic, and in the case of cocoa, they can be present at various stages of harvesting, fermentation, and storage. This is detailed in Table 9.

Table 7.
Fungi Species Present at Different Stages of Cocoa Processing

Fungi present at different stages of cocoa processing	Infection percentage during fermentation	Infection percentage during sun drying	Infection percentage during storage
Absidia corymbifera	4,94	26,19	31,83
Aspergillus candidus	0,06	2,19	1,43

A. carbonarius	0,06	1,48	2,40
A. clavatus	ND	0,04	ND
A. flavus	0,16	11,30	7,74
A. fumigatus	0,65	1,69	0,09
A. niger group	0,24	2,65	4,15
A. ochraceus group	ND	0,28	0,09
A. parasiticus	0,10	5,65	2,22
A. penicillioides	ND	ND	2,20
Aspergillus sp. nov.	0,24	18,25	14,20
A. sydowii	0,06	0,35	2,58
A. ustus	ND	ND	0,05
A. versicolor	0,06	ND	1,71
Ascomycetes	0,12	0,04	ND
Cladosporium sp.	ND	ND	0,05
Dematiaceous hyphomycetes	0,06	3,09	0,28
Emericella nidulans	ND	ND	0,18
Eurotium amstelodami	0,84	0,51	12,32
E. chevalieri	ND	1,13	2,97
E. rubrum	ND	0,92	7,37
Eupenicillium sp.	ND	ND	0,51
Fusarium solani	ND	0,04	ND
Geotrichum candidum	9,14	5,10	0,78
Monascus ruber	3,69	0,56	1,66
Mucor sp.	0,53	0,11	0,23
Neosartorya fischeri	ND	0,11	0,09
Paecilomyces variotii	0,24	0,41	0,69
Penicillium citrinum	ND	2,96	1,75
P. fellutanum	ND	ND	0,51
P. paneum	2,69	17,31	3,37
Rhizopus sp.	0,16	1,06	0,74
Syncephalastrum sp.	0,06	ND	2,82
Wallemia sebi	ND	ND	0,32
Yeast	28,12	20,33	3,42

Source: Authors' own elaboration based on Copetti et al. (2011).

The main use of cocoa is as a foodstuff. Consequently, good agricultural and processing practices are essential to obtain healthy beans, free from microorganism colonization and insect attacks. Examples of healthy beans are shown in Figure 30:

Figure 30.
Cocoa Beans Free from Microorganisms and in Good Condition

Source: Authors' own elaboration.

As fermentation allows biochemical processes initiated on the outside of the cocoa bean to transform its interior with new volatile molecules that give color, aroma, and taste, it is necessary to ensure that the cocoa beans are well fermented, i.e., they should maintain their characteristics across all genetic materials with some differences.

Adequate fermentation and drying of the cocoa bean must be verified by fracturing the entire seed of a freshly fermented cocoa bean, as shown in Figure 31.

Figure 31.
Freshly Fermented Cocoa Beans in the Processing Stage

Source: Authors' own elaboration.

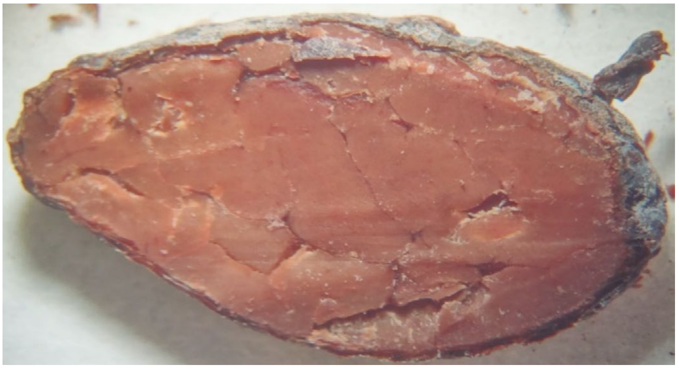
Drying is also evident in the color and texture of the bean. During this process, the dark brown color and cracking of the bean's grooves become more accentuated than during roasting or torrefaction, which forms the cocoa nibs. Figure 32 illustrates the kidney-like shape of a well-fermented and dried cocoa bean, where the biochemical process of proteolysis and the transformation of proteins into flavor and aroma precursors have occurred successfully within the bean.

Figure 32.
Kidney-Shaped Cocoa Bean without Husk, Post-Fermentation and Drying

Source: Authors' own elaboration.

Additionally, it is crucial to observe the color of the beans and their kidney-shaped or ridged form. Beans that are pale or white to gray, and smooth, indicate fermentation defects and will exhibit astringency. This is shown in Figure 33:

Figure 33.
Longitudinal Cut of Unfermented Cocoa Bean



Source: Authors' own elaboration.

In contrast, brown or purple-colored beans, depending on the genetic materials, indicate good fermentation, where the cotyledons have been fully transformed into flavor and aroma precursors demanded by consumers.

Figure 34.
Cocoa Beans with Characteristic Color

Source: Authors' own elaboration.

During the roasting process that yields cocoa nibs, the formation of grooves, characteristic of well-fermented beans, should be verified, as shown in Figure 35:

Figure 35.
Cocoa Nibs Formed after Roasting or Torrefaction

Source: Authors' own elaboration..

Conversely, slaty or unfermented cocoa beans have a shiny, smooth appearance similar to old-fashioned chalkboards. This formation occurs during harvest, when cocoa beans harvested on different days are mixed and not immediately prepared for fermentation, causing the cocoa beans to dehydrate. This phenomenon is illustrated in Figure 36:

Figure 36.

Granos pizarrosos de aspecto oscuro brillante

Source: Authors' own elaboration..

Through a visual inspection, the cutting test allows for the determination of the appearance of the cocoa bean. Table 8 summarizes these characteristics.

Table 8.

Evaluation of Cocoa Beans. Cutting Index

Color	Cause
Slaty	Unfermented
Violet, compact texture	Low fermentation
Violet, open texture	Good to slightly low fermentation
Brownish-violet to brown	Good fermentation
Brown	Over-fermented

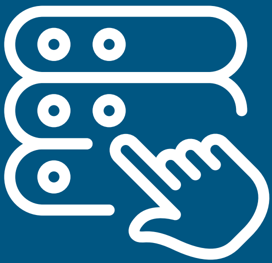
Source: Stevenson et al. (1993).

Accordingly, the cutting test evaluates the entire post-harvest process and assesses whether fermentation, drying, and storage have been carried out properly. It should be noted that this is a sensory test that requires trained field operators to perform it accurately. Currently, there are several methodologies for evaluating fermentation indices using analytical methods, such as color measurement by spectrophotometry and spectro-colorimeters.

In conclusion, this chapter aims to serve as a guide for understanding the significance of physical quality indicators, encourage stakeholders in the cocoa production chain to implement them, and elucidate the main actions to be considered in the physical evaluation of cocoa. This includes assessing the efficiency of the fermentation process, whose transformation of biochemical compounds inside the bean alters the texture, color, and shape of the cotyledon. These are characteristics of the fermentation percentage, which determines the quality of cocoa and its commercialization in domestic and international markets. It is also hoped that there will be a better understanding of aspects such as moisture content related to proper drying. This distinction is vital, as cocoa with a moisture content of 7 % can be stored in bulk for over 3 months, ensuring the product's safety as a food item. In contrast, cocoa with higher moisture levels fosters the growth of fungi and bacteria that deteriorate its physical, chemical, and sensory properties, and thus, its overall quality.

CHAPTER 5

EVALUATION OF THE SENSORY QUALITY OF COCOA



This chapter explores the importance of selection, training, and compliance with established standards for the execution of sensory analysis. These elements are key to ensuring the final quality of the product and achieving consistent characteristics so that the end consumer receives a standardized product. This is particularly relevant for fine flavor and aroma cocoa, as well as for specialty cocoa. Sensory analysis thus becomes the focus for Colombian cocoa producers and processors, serving as a useful tool for decision-making during crop establishment, post-harvest processes, and cocoa product development.

As a food science, sensory evaluation is crucial for the development of the food industry. In the case of cocoa, it must be approached with scientific rigor, considering the following aspects for its proper execution.

5.1 SENSORY EVALUATION OF FOOD

Following sensory perception, both the evaluator and the consumer form a conscious judgment about what they perceive in a raw material, a product in process, or a finished product. They then assess the quality of attributes based on their intensity and quality. If the perceived sensation is positive, the product will be accepted; if the sensation is negative, the product will be rejected (Chambers, 2019). Generally, based on their individual perceptions, people make judgments about the foods they eat or drink using various rating scales to classify them into categories. Hence, the presentation of a food product to consumers is based on decisions made through different sensory methods that evaluate desirable attributes and detect undesirable characteristics.

To ensure that the judgments made by an evaluator—whether a consumer or a trained professional—are consistent over time, a series of methodologies have been established to confirm acceptance or rejection in a manner that is appropriate, consistent, and scientific (Kemp, 2008).

In the food industry worldwide, sensory evaluation is considered crucial for making decisions about a food product before it reaches the final consumer. The quality attributes of these foods are determined by their aroma, flavor, taste, tactile properties, and appearance.

One of the most commonly used definitions of sensory evaluation comes from the Institute of Food Technologists (IFT) in the United States, which is a community of professionals and students playing an essential role in food science and innovation in the quest to ensure a safe, nutritious, and sustainable global food system. Since 1939, the IFT has been a space for science and knowledge development among food professionals and technologists who want to learn, contribute, be inspired, and transform collective scientific knowledge into innovative solutions for the benefit of people worldwide. IFT defines sensory evaluation as “a scientific disciple used to evoke measure, analyze, and interpret reactions to those characteristics of food and materials as they are perceived by the senses of sight, smell, taste, touch, and hearing” (Sensory Evaluation Division of the Institute of Food Technologists, 1975).

The Association Française de Normalisation (French Association for Standardization, AFNOR in French) is another benchmark in food science and process standardization. Established in 1926, it is governed by the French law of 1901 and consists of nearly 2,500 member companies. It aims to lead and coordinate the standardization process and promote the application of AFNOR standards in food. AFNOR defines sensory evaluation as: "The examination of the organoleptic properties of a product by the senses" (Cordero, 2013) [Quote translated from its original in Spanish].

With new trends in mass food production and the emergence of the science of food sensory evaluation, various sensory techniques have been developed to ensure the organoleptic and nutritional quality of a food product before offering it to the end consumer (Chambers, 2019b).

Sensory tests have been developed from different scientific disciplines, considering psychological, physiological, cultural, chemical, biological, and statistical aspects to establish protocols to evaluate and quantify, through scales, flavor intensity, color, and texture. To this end, sensory tests are classified into three major groups: discrimination testing, descriptive tests, and affective tests, as shown in the following table:

Table 9.

Classification of Testing Methods in Sensory Evaluation

Classification:	Objective of the test	Question of interest	Characteristics of panelists
Discrimination test	To determine if two products are perceived differently by the consumer.	Analytical. Are there any differences between the products?	Selected due to their sensory acuity, knowledge of technical standards, and some training.
Descriptive	To determine the nature of sensory differences.	Analytical. In what specific characteristics do the products differ?	Selected due to their sensory acuity and supported by technical standards and highly trained methods.

Classification:	Objective of the test	Question of interest	Characteristics of panelists
Affective	To determine the acceptability of a food product.	Hedonic. Which products do you like the most and which are your favorites?	Selected to evaluate a product without prior training.

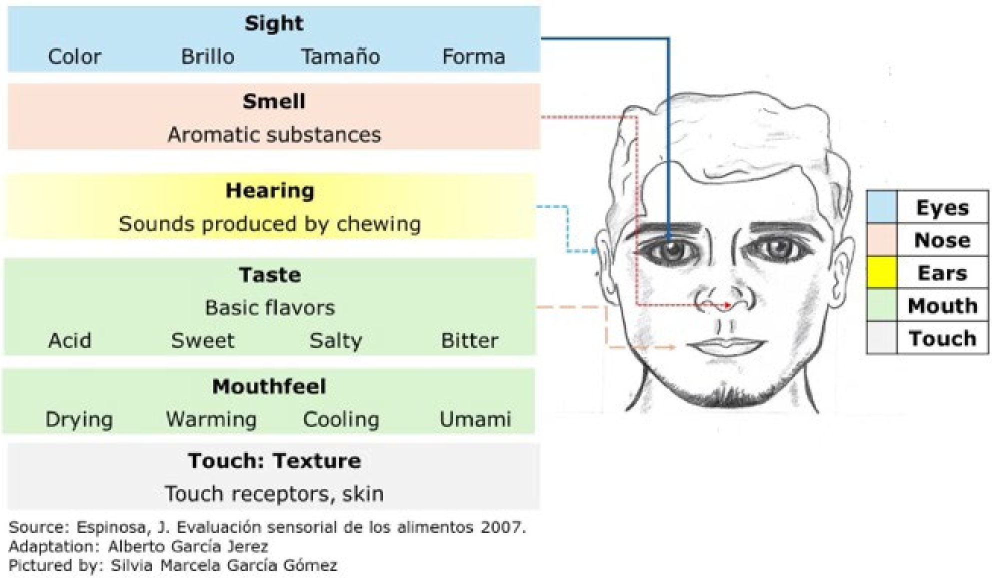
Source: Chambers (2019).

5.2 SENSORY PERCEPTION

The sensory perception process is the mechanism by which a consumer expresses the characteristics of a food. It includes several stages: first, the color, appearance, or look is perceived using the sense of sight; then, the odor with the sense of smell; later, the texture using the sense of touch; after that, the flavor with the sense of taste; and, finally, the sound produced while chewing and swallowing with the sense of hearing (Espinosa, 2007).

Figure 37.

Diagram of Sensory Perception of Food Substances



Source: Espinosa (2007).

In the sensation stage, stimuli can be chemical or physical and are received through the sensory organs. These sensations are then transmitted through the nervous system, and the brain interprets them to generate a perception of the product. By correlating this with previous experiences, an acceptance or rejection response is given based on the intensity, duration, and quality of the stimulus (Drake, 2007).

Perception is a complex system involving the physiology of sensory signals received from the environment through multiple specialized sensory receptors. These receptors translate signals into electrochemical stimuli to determine changes in the membrane of specialized receptor cells and induce an "action potential" or depolarization of the cell membrane. This action involves the exchange of chemical substances (ions) from the outside to the inside to generate the electrochemical impulse. This activity occurs in the receptors of living organisms. In humans, specifically, action potentials travel through afferent neurons or the peripheral nervous system and are centralized in the central nervous system (spinal cord, cerebellum, diencephalon, and cerebrum). Information is analyzed in the central nervous system and then travels to different centers for response or further analysis. Table 10 lists the types of stimuli and the receptors that perceive them.

Table 10.

Classification of Stimuli and Types of Receptors

Stimuli	Types of receptors
Mechanical	Mechanoreceptors: respond to physical deformation of the cell membrane from mechanical energy or pressure, including touch, stretching, movement, or sound.
Acoustic	Sound: wave propagations through air or solids such as teeth and bones.
Thermal	Thermoreceptors: respond to heat or cold (on the skin).
Light	Photoreceptors: respond to radiant energy (eyes, visible light in most vertebrates; visible light and UV in many insects).
Chemical	Chemoreceptors: (tongue and smell) respond to specific molecules, often dissolved in a particular medium (such as saliva or mucus) or molecules in the air.
Electrical	Nociception is a neural process that encodes and processes potentially harmful stimuli against tissues.

Source: Lee and Owyang (2017).

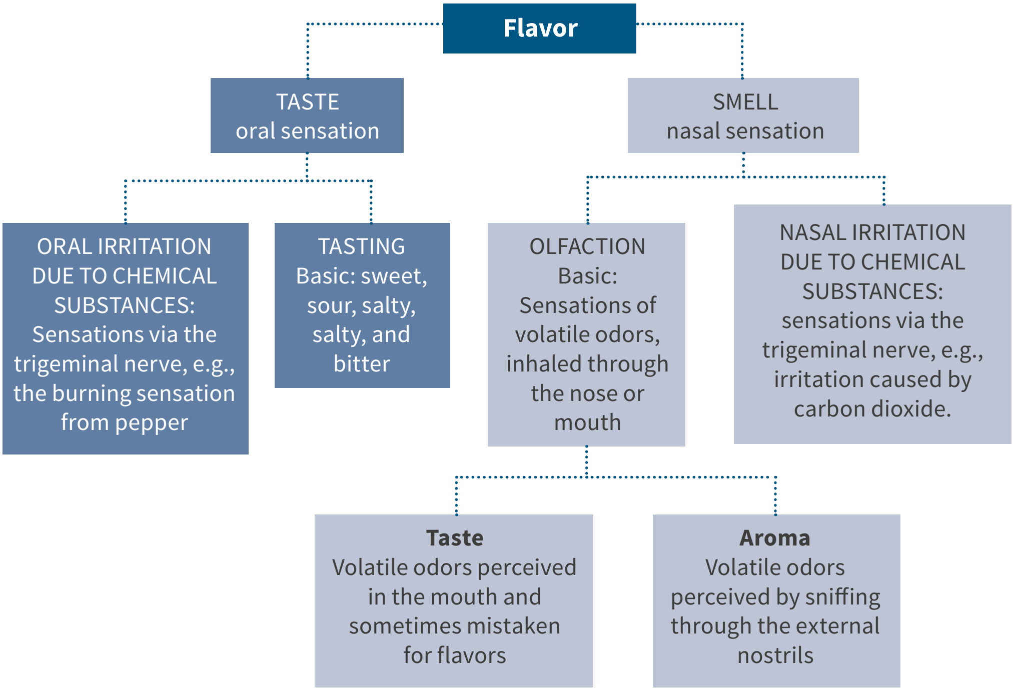
Specifically, perception begins with an initial sensory stimulus, or olfaction, in humans, which influences the choice of a food before consumption. Usually, volatile molecules activate the olfactory receptors, which, together with sight, determine the visual appearance of a food and whether it is to the consumer's preference (Leite et al., 2013). In turn, the sense of taste complements the sense of smell to amplify the information of the food and produce flavor, which is the interaction of these two senses. When food is in the mouth, chewing activates sensory stimuli through the sound produced by the mechanical action of chewing. This sound is perceived by the ear through the Eustachian tubes, starting in the outer ear when the mouth is opened and passes through bone conduction at a higher speed of sound up to the middle ear. Another sense that evaluates food when it is perceived by the hands and then the mouth is touch. It involves a large group of receptors including those of kinesthesia, i.e., movement and position (muscles and joints), precision in the dental alveoli, temperature, and pain, among others.

Flavor denotes the perceptible organoleptic properties of foods through the olfactory organ primarily, but when combined with taste, a person can appreciate the volatile molecules diluted in saliva, sensorially creating a library of flavors. The term “flavor” also denotes a complex set of olfactory and gustatory properties perceived when tasting, which can be influenced by tactile, heat-cold, painful, and kinesthetic effects. The British Standards Institution defines flavor as the combination of taste and odor that can be influenced by painful, cold, and tactile sensations (NTC 3501, 2004).

Flavor perception occurs in three stages:

- Evaluation of the odor: by inhaling the aroma of the food product before it enters the mouth.
- Evaluation of flavor in the mouth: when the food product is in the mouth.
- Evaluation of aftertaste: sensations perceived after swallowing a sample of the food product.

Figure 38.
flavor



Source: Authors' own elaboration based on Lawless (1990).

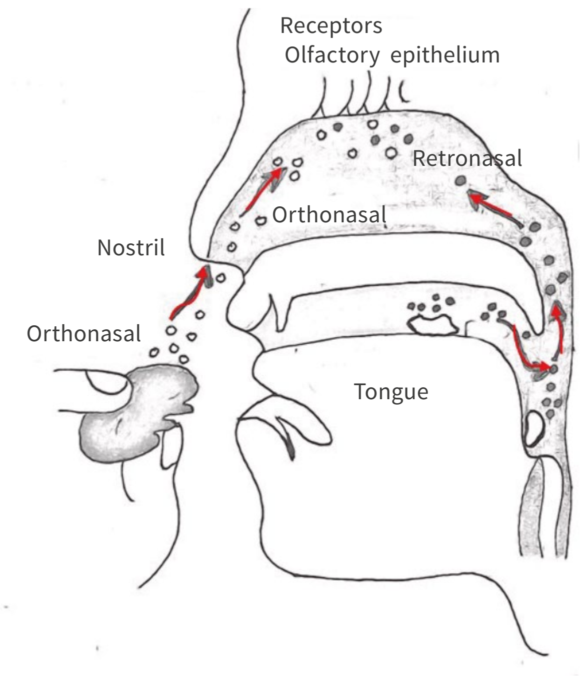
Flavor perception varies significantly from person to person, even among those trained as expert tasters. These physiological characteristics may be determined by the intensity of perception of aromas or pathological abnormalities such as anosmia, which alters the olfactory bulb or centers in the brain responsible for interpreting information from odorant molecules. When anosmia is present, the ability to perceive flavors in foods diminishes or is lost, and the sense of taste, detected by the receptors on the tongue, is insufficient to interpret the full range of flavors processed by the brain (Rolls, 2020).

As previously mentioned, the sense of smell is the primary sensory system that helps make the initial decision to consume food based on aroma perception. Aromas are volatile molecules from foods playing a crucial role in deciding whether or not to eat something. The aroma and molecules of foods, whose sensory characteristics represent their odor, are given by substances such as esters, which, combined with other molecules, produce volatile compounds, such as fruit aroma. Flavor precursor molecules, perceived through smell and taste, include aldehydes and ketones, which, in the case of specialty cocoa, enhance its quality.

The senses of smell and taste are closely linked through the receptors of the tongue allowing the generation of flavor. Orthonasal perceived odors enter through the nose (nostrils) and travel directly to the olfactory epithelium in the nasal cavity. The retronasal perception of odors are produced by mechanical actions in the mouth, allowing volatile molecules from the food to be released and travel through the nasopharynx at the back of the oral cavity to the nasal cavity, where they reach the olfactory epithelium (as shown in Figure 39).

Figure 39.

Taste Perception in the Mouth and Nasal Cavity



Source: Authors' own elaboration.

5.3 ESTABLISHING A PANEL OF EVALUATORS FOR SENSORY ANALYSIS

From the interdisciplinary dimension of sciences and disciplines such as psychology, physiology, anthropology, statistics, biology, or chemistry, sensory evaluation is based on human sensory perception, mainly of evaluators who conduct sensory analysis.

This foundation allows for the continuous assessment of the environment and the study of consumer trends regarding a product. Hence the importance of objectivity in sensory evaluation and its basis in procedures specific to these disciplines.

As a scientific discipline responsible for food analysis, sensory evaluation dates back to the 1940s, when systematization in food production and the establishment of world-renowned food product brands took off (NTC 3929, 2009).

Sensory analysis is a measurement process involving equipment and facilities, but its main component is the people or evaluators conducting the tests. Evaluators require ongoing training and usually specialize in a particular food product. This group can be external, i.e., people outside the organization are brought in for this role, or internal, i.e., the staff within the organization who, due to work and logistical reasons, are more available for conducting tests (Sharif et al., 2017).

In sensory analysis, how data is collected for subsequent analysis is crucial. According to experimental design, protocols associated with this activity should be considered and should be known to the panel members.

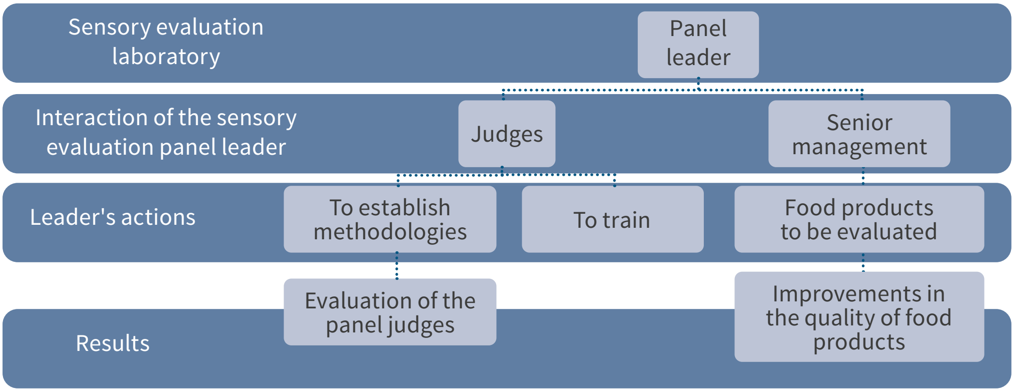
As mentioned earlier, members of the sensory evaluation panel usually work within the same organization. However, sometimes, other priority tasks may force judges to sideline sensory evaluation activities and panel work. Therefore, senior management of the organization, as part of its quality processes, must establish policies to form and maintain the panel for the sensory evaluation of manufactured food products.

The coordination of the sensory evaluation panel requires the presence of a "panel leader," a person responsible for planning laboratory activities, sample preparation, scheduling judges for tastings, and compiling and analyzing information (Icontec GTC 178-1, 2009).

In a sensory evaluation laboratory with a panel of judges, it is important to have a sensory evaluation panel leader who coordinates which products will be evaluated, the sensory techniques to be used, schedules for judges to evaluate samples, logistics related to sample presentation (type of containers, sample coding, presentation of forms, ideal sample temperatures, light control, and comfortable environment for sample evaluation, etc.), result analysis, and report presentation The leader is also responsible for holding regular meetings with the judges to discuss evaluation exercises and for communicating with management and quality committees (Chambers, 2019).

Figure 40.

Roles and Responsibilities of the Sensory Evaluation Panel Leader



Source: Authors' own elaboration.

The relationships among the judges, the panel leader, and laboratory assistants should be harmonious and based on strict sample evaluation protocols, clear behavioral rules during testing, and rigor in data recording (Stone et al., 2012).

The NTC, through the Colombian Technical Guide (GTC in Spanish) 178-1 of 2009, provide guidelines for sensory analysis, a general guide for sensory evaluation laboratory personnel. Part 1 describes the responsibilities of the personnel of a sensory evaluation laboratory. Part 2 describes the recruitment and training of panel leaders. This regulation provides the necessary basis to ensure that the selection process of the leader is carried out based on their competencies.

Selecting candidates for a sensory evaluation panel is an ongoing process that requires a pre-selection survey as an initial filter for the number of people interested in participating. Table 13 describes the key aspects for this activity.

Table 11.

Relevant Aspects in the Pre-selection Survey for Sensory Evaluator Candidates

Characteristic	Justification
Age	Younger individuals generally have a lower threshold for detecting odors and tastes, as well as low thresholds to touch, hearing, and sight.

Characteristic	Justification
Sight, hearing, taste, touch, and smell	These determine the functional state of sensory organs, implying the reliability of sensory evaluation. They are complex receptors that transmit information to the brain for interpretation.
Allergies	Allergies to certain foods can affect health due to immune responses. Exposure to odors or ingestion can cause mild reactions or anaphylactic shock, leading to decreased blood pressure or even death.
Respiratory diseases	Conditions like anosmia (loss of smell) or ageusia (loss of taste) can affect sensory perception of food. While usually temporary, they impact food sensory evaluation.
Habits affecting sensory perception	Smoking, drinking alcohol, excessive coffee or spicy food intake can increase the threshold for detecting food-related molecules. Higher concentrations of aromas, flavors, textures, etc., are needed to be perceived.
Level of education	The educational and technical or university background influences the training strategies for the panel of judges.
Interest in the product being evaluated	The sensory evaluation panel is a measurement tool usually specialized in a specific food product, such as coffee, cocoa liquor, wine, beer, dairy products, among others. Hence the importance of motivation to evaluate a food product.
Willingness to receive ongoing sensory evaluation training	This is an ongoing process. Training, the implementation of new methodologies, or simply participating in discussion tables within the panel forces members to constantly learn.
Availability of time	Most sensory evaluation judging panels are made up of members of an organization who perform various roles and tasks. Thus, it is important to assess the candidate's availability for panel activities.

Source: GTC 165 (2014) and GTC 178-1 (2009).

5.4 BASIC CONDITIONS FOR ESTABLISHING A SENSORY EVALUATION PANEL

These conditions are determined by an organization's interest in understanding that this activity supports research processes and, consequently, represents an investment that, in the short term, enhances the quality processes of food products and increases profits.

To accurately understand how industrial or production processes behave, it is necessary to quantify or measure information that enables decision-making in the food industry. A panel is an analytical tool that positions products in the market and opens doors to innovations in raw materials and products.

Members of a sensory evaluation panel are individuals engaged in continuous training and learning. Their evaluations, combined with statistical and mathematical interpretation, enable the creation of food attributes or the construction of flavor profiles.

When a sensory evaluation panel has a dedicated space for its activities, partnerships with other sensory panels can be established. This collaboration between laboratories within the same fields of expertise is known as "interlaboratory testing," which, in this context, refers to those focused on cocoa and chocolate product testing.

In the past five decades, sensory evaluation of food for human consumption has been associated with quality processes, including measurements, analyses, testing, implementation of new methodologies, and continuous improvement of food products.

As previously mentioned, a sensory evaluation panel consists of trained individuals who assess through sensory organs, validate data with statistical methods, and construct mathematical algorithms to predict consumer behavior across different regions, social classes, ages, economic strata, beliefs, and education levels regarding a specific product.

Consumer sensory evaluation and the analysis of such information determine a product's acceptance or rejection. Consequently, studies on shelf life, new product development, packaging presentation, color selection, and design formats are promoted.

Consumers perform sensory analyses, meaning they evaluate products using their sensory organs and preference tests to determine acceptance or rejection. Descriptive or analytical sensory evaluation predicts these preferences within a target social group.

5.5 REQUIREMENTS FOR CONDUCTING SENSORY TESTS

When members of a sensory evaluation group are part of an organization or are external but do not have exclusive hours allocated for this activity, it is important to create schedules that include specific days and times for attending the sensory analysis laboratory to conduct scheduled tests.

For scheduling panel judges, it is crucial to plan sessions at times that do not coincide with meal times such as breakfast or lunch. Ideal times are between 9:00 and 11:00 a.m. in the morning and between 3:00 and 6:00 p.m. in the afternoon.

Descriptive analysis requires 6 to 8 judges, and it is recommended to evaluate each sample in triplicate. This condition is vital for ensuring the validity of statistical calculations, whether for generating a profile or conducting Principal Component Analysis (PCA).

Ideally, a sensory evaluation panel should have 15 available judges. Therefore, continuous training and the inclusion of new participants are important. This training and coaching of judges require several hours over multiple years (Silva et al., 2014).

5.6 THE SENSORY EVALUATION LABORATORY

The concept of a sensory evaluation laboratory is related to a space designated for conducting sensory analyses. The ideal laboratory should include a sensory testing room with booths, a sample preparation area equipped with essential items such as industrial sinks, stainless steel or marble counters, lighting, air conditioning, refrigerators, blenders, cooking utensils, and laboratory analytical equipment such as pH meters, analytical balances, volumetric glassware (graduated pipettes and burettes) and calibrated volumetric glassware (flasks) to prepare food samples and perform basic physical and chemical analyses.

Depending on the specialization of the food analysis, for example, cocoa liquor, a sensory evaluation laboratory must be equipped with water baths (bain-marie), rotary ovens, hulling machines, general-use laboratory ovens, refining mills, rheometers, pH meters, micrometers, etc.

A sensory evaluation laboratory can provide various types of food analyses, including microbiological, rheological, texture analysis, color analysis, product shelf-life studies, and, of course, sensory analyses through a sensory evaluation panel.

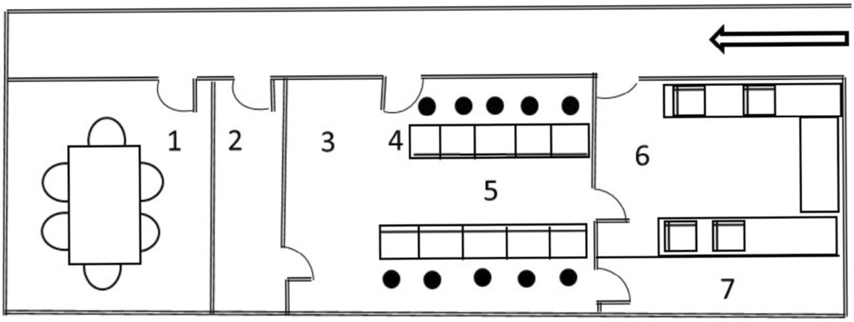
Other important areas in a sensory evaluation laboratory include: a storage room for supplies, a cleaning supplies and sample storage room, a sample reception area, a waiting room, a discussion room, the laboratory leader's office, and space for a refrigerator or freezer to preserve samples. Additionally, a meeting room for the sensory evaluation panel team is essential. GTC 226 of 2012, in its guide for designing testing rooms, outlines the areas a sensory evaluation laboratory should have, including a sample preparation area, a waiting room, an office, a meeting room, a storage room, and a sample storage area.

The sensory evaluation laboratory must comply with technical standards and quality management systems such as Good Manufacturing Practices (GMP) and Hazard Analysis and Critical Control Points (HACCP), adopted by the Codex Alimentarius Commission (CAC), to ensure food safety. Special attention must be paid to regulations for the product sample preparation and processing processes.

The services offered by a laboratory should align with its specialization, establish a quality management system, comply with NTC standards, achieve accreditation for tests in NTC-ISO/IEC 17025 or general requirements for the competence of testing and calibration laboratories, GTC 226-2012 (ISO 8589) for sensory analysis, the general guide for the design of test rooms, and GTC 165-2014 (ISO 6658) for sensory analysis. They will also align with NTC 226, which is the governing standard for designing testing rooms in a sensory evaluation laboratory, which includes designing laboratory booths and other areas, as shown in the following figure:

Figure 41.

Testing Room Layout According to GTC 226



Note. 1. Meeting room; 2. Office; 3. Team workspace; 4. Testing booths; 5. Distribution areas; 6. Preparation area; 7. Storage room. Source: GTC 226 (2012).

The sample preparation area (6) is exclusively for the panel leader, assistants, and laboratory technicians conducting the analyses. Samples are prepared and delivered to the judges through small windows connecting the laboratory. This setup is illustrated in Figure 42.

Figure 42.

Sample Preparation Area and Windows Connecting with the Judges' Booths

Source: Authors' own elaboration (SENA Gautiguará panel).

The testing booths are connected to the sample preparation area via small windows. The booths prevent judges from perceiving each other, thus eliminating misjudgments caused by cross-perception that the brain interprets through mirror neurons at the cortical and limbic system levels.

The estimated number of booths ranges from 5 to 10, either arranged facing each other or in an L-shaped layout, constructed with permanent materials. Portable booths are also an option for conducting tests at different locations while maintaining the same principle of blocking sensory perception of external stimuli and conditions to ensure judges' concentration and comfort (GTC 226, 2012).

The color and brightness in the sample presented to the judges can influence their decisions on the perception of a food. To mitigate these visual phenomena caused by light refraction and eliminate incorrect sensory evaluation, uniform lighting is required to mask the colors and textures of the sample, as shown in Figure 43.

Figure 43.
Fully Individualized Sensory Evaluation Booths with Color-Blocking Lights

Source: Authors' own elaboration (SENA Gautiguará panel).

In the testing booths, the labeled sample is presented with a form for recording the evaluation (half-letter size), a pencil or pen, a glass of water for mouth rinsing, spoons, and a sink for mouth rinsing. The chair should be comfortable and not produce distracting noises for the judges. Other sound stimuli are minimized in the booth environment, first through the judges' discipline and second by avoiding the presence of individuals not involved in the tests. Odor stimuli that could alter sample evaluation are controlled in the testing area by creating passive pressure to prevent the entry of external aromas and their mixing with the sample's aromas.

5.7 TYPES OF TESTS IN SENSORY EVALUATION OF FOODS

Sensory evaluation is an interdisciplinary science that combines the understanding of human physiology, biochemistry, biophysics, sociology in the social component of food, chemistry, statistics, mathematics, and anthropology. For example, anthropology can contribute to the study of spicy foods in Central America. This interdisciplinary approach has led to the universalization of flavors, aromas, and other attributes (e.g., a beer brand maintaining its characteristics globally).

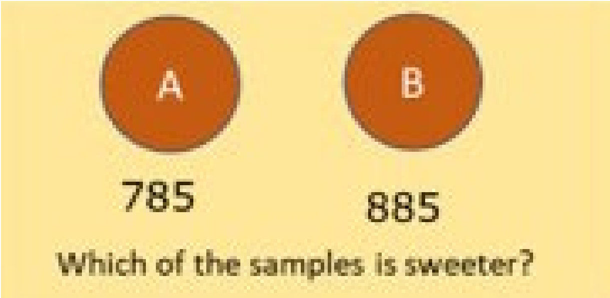
A trained sensory evaluator can easily recognize basic flavors and specializes in attributes and sensory analysis in areas such as raw material description, new food product development, quality control, and shelf-life studies to establish expiration dates. Thus, it is emphasized that panel evaluators are analytical tools that require constant calibration, i.e., ongoing training to remain reliable and valid (Drake, 2007).

Sensory tests assess the color, flavor, odor, and texture of foods using discriminative and descriptive analysis methods, including the following:

Paired test: The principle of this test involves presenting panelists with two samples or pairs of samples to identify the characteristics of a product. For example, comparing two juices or nectars from different brands, according to “NTC 2680 of 2013. Sensory Analysis. Methodology. Paired Comparison Test,” ISO 6658:2005, and GTC 165 of 2014-08-20 (as shown in Figure 44).

Figure 44.

Submission of Coded Samples for Paired Testing



Source: NTC 2680 (2013).

The paired test sample must be accompanied by an evaluation form containing specific information about the test, which must be clear and specific to the product being evaluated. The code labeled on the sample containers must match the one on the form, as shown in Table 12 and Figure 45.

Table 12.

Paired Test Evaluation Form

Name: ______________________	Date: ______________________
Product: Commercial Juices	
You have two samples marked with numbers. One of them is sweeter. Mark with an X the sample you consider sweeter: 785 885 ☐ ☐	
Remarks: ______________________________	
Thank you!	

Source: NTC 2680 (2013).

Duo-Trio Test: This method is used for detecting subtle differences. Three samples are presented simultaneously to the panelists. One sample is marked as the reference sample with the letter "R," and two coded samples, one identical to the reference sample ("R") and the other different. NTC 3883 on sensory analysis is used as a reference for this test. The 2006 duo-trio test is ideal for training candidates and continuous use in sample evaluation (Zoecklein et al., 2008; NTC 3883, 2006). This is illustrated in Figure 45.

Figure 45.

Presentation of Samples for the Duo-Trio Test

Source: NTC 3883 (2006).

The duo-trio test is accompanied by an evaluation form providing precise information on how to evaluate the identical codes found on the sample containers, as shown in the following table:

Table 13.

Duo-Trio Test Evaluation Form

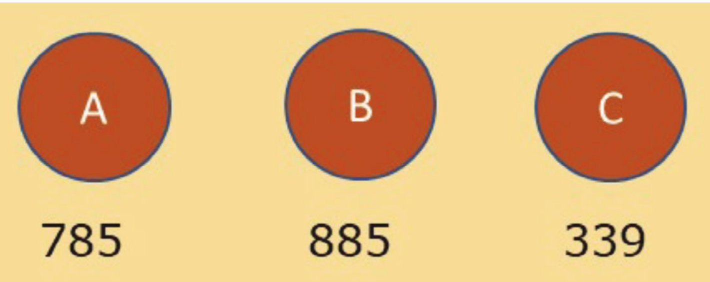
Name: ______________________	Date: ______________________
Product: Cocoa Liquor	
You have one reference sample marked with an "R" and two other samples marked with numbers.	
One of these samples is identical to R, and the other is different. Which of the two samples is different from R?	
Mark with an X 785 885 ☐ ☐	
Remarks: ______________________________	
Thank you!	

Source: NTC 2680 (2013).

Triangle test: This test involves presenting three samples, two identical and one different. Small differences between the samples are detected, and the intensity and identification of the different sample are assessed (Radovich, 2004). It consists of three labeled and coded samples for evaluation by a sensory judge in training or an expert. The "NTC 2681 Sensory Analysis. Triangle Test" is used as a reference.

Figure 46.

Presentation of Samples for the Triangle Test



Source: NTC 2681 (2006).

It is important that the perceptibility detected by the judge is recorded in a form that includes or selects the codes corresponding to the samples, as shown in the following table:

Table 14.

Triangle Test Evaluation Form

Name: ______________________	Date: ______________________
Product: Cocoa Liquor	
You have three samples of cocoa liqueur, two of which are identical. Mark with an X the different sample: 785 885 339 ☐ ☐	
Remarks: ______________________________	
Thank you!	

Source: NTC 2681 (2006).

Through this type of sensory testing, organizations can make decisions to define raw materials, develop new food products, or evaluate products on the market.

Sensory evaluation panel tests, experimental designs, sample processing methods, and statistical analysis are increasingly required by industries and organizations operating in different countries. In addition, networks of laboratories specialized in products of interest such as soft drinks, dairy products, wines, beer, etc. have been established.

All sensory evaluation laboratories are governed by international standards set by organizations that accredit procedures, methods, and methodologies globally. The British Standards Institution (BSI), The International Organization for Standardization (ISO), and The American Society for Testing and Materials (ASTM) are among the organizations that have been pioneers in food industry research or standardization processes for several decades.

Sensory evaluation panels are considered highly reliable instruments due to their training, rigorous scientific approach, and the handling and processing of obtained information. Table 15 summarizes the types of descriptive sensory tests used by various industries worldwide (Zoecklein et al., 2008).

Table 15.
Summary of Sensory Evaluation Panel Tests

Tests	Use	Examples	Basic methods
Triangle Test	Multipurpose	Three coded test samples. Two samples of the same product (A) (coded differently), and one of a different product (B).	Judges evaluate all three samples, then choose the sample that is different from the other two, or the one that is not correct.
Duo-Trio Test	Comparison with a reference purpose	One reference sample (Ref. or R). Two coded samples (A, B): “A” is the same product as the reference product (control product).	Tasters evaluate the reference (Ref.), then the two test samples (A, B). The judge is asked to indicate which test sample is the same as the reference sample. Serving order: Ref. AB, Ref. BA.

Tests	Use	Examples	Basic methods
"B" is the sample for	When a difference is known	Two coded test samples (A, B). One is known to be chemically higher in an attribute (e.g., sweetness).	The judge is asked to identify which sample is higher in an attribute (e.g., to identify which sample is sweeter). Serving order: AB, BA.
testing.	Tasters evaluate the reference (Ref.), then the two test samples (A, B).	Dos muestras de prueba codificadas (A, B).	El juez evalúa ambas muestras e indica si cree que las muestras son iguales o diferentes. Órdenes de servicio: AB, AA, BA, BB. Nota: se presentan dos servidas a cada juez.
Same / Different	When the difference is unknown	Two coded test samples (A, B).	The judge evaluates both samples and determines if they are the same or different.
Paired Preference Test	Which product is preferred	Two coded test samples (A, B).	The judge evaluates both samples and choose their preferred one. Only one choice is made.

Source: Compiled by authors based on Zoecklein et al. (2008).

5.8 BIASES OR ERRORS IN THE SENSORY EVALUATION OF FOODS

When a sample is evaluated by an evaluator or a panel of evaluators, inadequate conditions may introduce biases or errors that affect the evaluator's judgment. To prevent such biases, it is essential to strictly adhere to methodologies according to the protocols established by standards and technical guides, which give recommendations to ensure appropriate environments, well-presented samples, and well-trained evaluators who understand the importance of conducting the tests accurately.

In general, a sensory evaluation panel is an analysis tool that requires constant training and ongoing education on the products being evaluated and the methodology applied. It is important to understand that a sensory evaluation panel is made up of people whose evaluations allow to make decisions in the food industry (Drake, 2007).

The importance of a sensory evaluation panel lies in its ability to generate reproducible and repeatable judgments by evaluating samples multiple times and minimizing errors that might affect the evaluation of a product's specific characteristics, no matter how minor. The members of the sensory evaluation panel have skills acquired through continuous training and ongoing education on the methodology used according to technical standards, the use of technical language for interpreting information, and analyzing results.

To minimize the risks associated with a sensory evaluation panel, behavioral protocols in the testing area and overall activities as a sensory evaluation judge in training or an expert must be established. Common psychological errors or biases include:

Expectation: Information provided to the judges in advance that limits the focus on the perception of attributes through the senses.

Position or marking: Inefficient presentation of the sample when served or confusing instructions. Evident markings on coded labels with different colors, using multiple handwriting styles, or ambiguous writing of numbers (e.g., zero "0" which can be confused with eight "8," or two "2" with nine "9") are also considered biases. To eliminate these errors, samples should be separated, labeled with readable tags, use standardized handwriting, and have correct descriptions of printed codes on evaluation forms (Chambers, 2019).

Logical errors: Making decisions based on minimal and subtle characteristics of the sample without fully evaluating it.

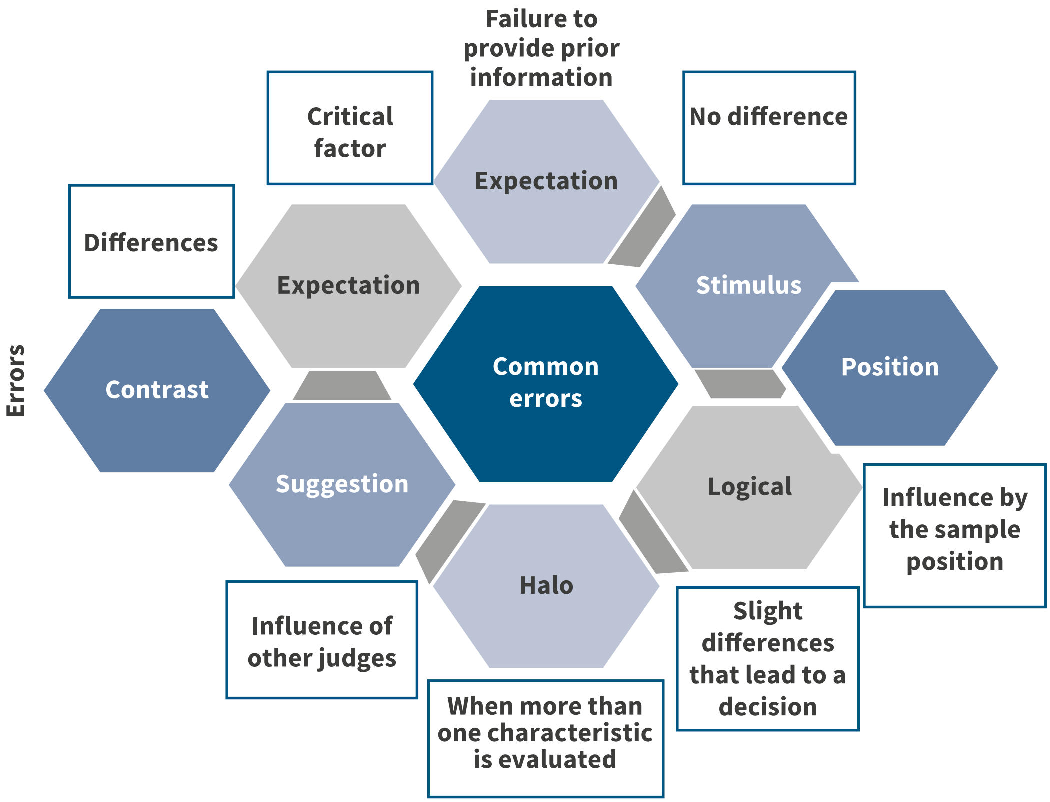
Halo or proximity effects: Occur when evaluating several characteristics simultaneously to define the attributes of a food (acidity, astringency, specific flavors, etc.). For example, associating dark color with bitter taste.

Suggestion effect: Comments made before entering the testing area or during the test, facial expressions of other judges, or external moods that affect the decision of the judge evaluating a sample.

Contrast effects: Small noticeable differences in samples that are not blocked, for example, the texture, color, or odors of a food.

Motivation: It involves psychological states, pressure from sample evaluation, lack of time to conduct the test, and health conditions that can impact results when evaluating a product. This may lead to losses or poor decisions in industries like winemaking, dairy, coffee, beer, among others.

Figure 47.
Psychological Biases that can Affect Judges



Source: Authors' own elaboration.

5.9 PROCESS OF FORMING A SENSORY EVALUATION PANEL

This process is crucial for an organization seeking to establish a panel of evaluators to measure the sensory quality of its products. It involves a significant financial effort to ensure suitable conditions and preselected, selected, trained, and evaluated personnel to meet the proposed objectives.

Once the panel of evaluators is established, the organization must develop a special training and monitoring plan for the evaluators' health status to ensure optimal performance conditions.

Initially, it is advisable to consider bibliographic references and current regulations to develop this process in a standardized manner, aiming for the panel to be accredited by the competent authority in the future. For example, the Norma Técnica 165 (Technical Standard 165), referencing ISO 6658, provides general guidelines for sensory analysis. Additionally, GTC 226 should be reviewed for guidelines on designing testing rooms, referenced with ISO 8589. Furthermore, the specific method to be implemented should be defined; in the case of cocoa, it is addressed in NTC 3929 for flavor sensory profiling, referenced with ISO 6564, and GTC 232 for sensory profiling referenced with 13299. These standards support the implementation of GTC 280 of 2017, which outlines guidelines for the selection, training, and evaluation of sensory evaluators, referenced with ISO 8586-1.

The process begins with a pre-recruitment awareness activity. This is followed by a survey containing questions that help the panel leader or leader conduct a selection process by verifying compliance with five requirements: health status, habits, availability, willingness, and preference for the product.

Once candidates are preselected, the selection process is planned, starting with basic tests for flavors, aromas, and colors, and discriminative tests such as paired, duo-trio, and triangle tests, which assess the candidate's ability to detect attributes and discriminative differences in the tests. When designing the tests, it is important to consider the panel's target product. The final selection of candidates for training can be supported by using the sequential analysis statistical technique available in the Colombian Technical Standard 5278 referenced from ISO 16820.

Specific training on the attributes of the target product begins with the selected group. It is recommended to start with training in the basic flavors of the product, then continue with training in specific attributes, and finish with acquired flavors or defects due to deterioration or contamination with substances not specific to the product. This process must guarantee the time and number of sessions necessary to achieve adequate training and include patterns or reference substances to help evaluators compare and memorize measurement scales. After training, it must be evaluated with test samples using appropriate statistical techniques. The panel leader is responsible for coordinating and conducting this training process and test sessions with known samples to foster good performance, trust, and confidence among evaluators.

5.10 FLAVOR PROFILE TEST

The NTC 3929 of 2009 on flavor sensory profiling presents two procedures for conducting a descriptive flavor analysis: the “consensus method,” where evaluation is done collectively to generate a single judgment, and where the panel leader is also one of the evaluators; and the "non-consensus method" or "independent methods," where each evaluator provides their judgment individually, and the evaluations are then consolidated.

In the independent method, evaluators first discuss their perceptions of the product's flavor in a group setting. Each evaluator then completes their individual evaluation form. Subsequently, the panel leader or coordinator consolidates these ratings and generates an overall report.

Figure 48.
Judge Evaluating Cocoa Liquor

Source: Authors’ own elaboration.

The methods are based on the concept that flavor consists of identifiable olfactory and gustatory attributes, and, on the other hand, a fundamental complex of non-identifiable attributes. The following steps are necessary to conduct a descriptive flavor analysis of a product according to NTC 3929 of 2009:

a) Identification of perceptible attributes.

b) Determination of the order in which these attributes are perceived. The order of presentation of the characteristics during tasting and the order of perception by the evaluator is recorded.

c) Evaluation of the degree of intensity of each attribute. The group of evaluators determines the intensity (quality or duration) of each characteristic. The most commonly used scales for classifying the intensity of characteristics are recommended as follows:

Table 16.
Intensity Rating Scales

0 =	Not perceptible
1 =	Begins to be perceptible or threshold
2 =	Weak
3 =	Moderate
4 =	Strong
5 =	Very strong

Source: NTC 3929 (2009).

d) Test of residual flavor or persistence of flavor, or both.

e) Evaluation of the overall impression. The overall impression is a general assessment of the product considering whether the olfactory and gustatory parameters are adequate, as well as their intensity and the degree of harmony perceived. This evaluation considers the harmony of the different attributes to give a better impression. This overall impression fundamentally falls into a three-point scale:

Table 17.
Evaluation of the Overall Impression

3	High
2	Medium
1	Low

Source: NTC 3929 (2009).

In the consensus method, the panel agrees on an overall impression. In the independent method, each evaluator rates the overall impression separately and then the average is calculated (NTC 3929, 2009).

5.11 SAMPLE SERVING

Regarding sample serving, before submitting a sample, it is advisable to first verify the physicochemical quality of the cocoa liquor to ensure that the sample is suitable for evaluation and falls within normal parameters. This optimizes the evaluation process of consistent samples. Additionally, it is important that the equipment used in the sample preparation process is included in a metrological program to ensure its maintenance and calibration. The presentation of samples is crucial for a proper product evaluation. Thus, the following aspects should be considered:

- **Temperature:** The temperature of the cocoa liquor must be between 50°C – 55°C. Once the sample is served, the evaluator must taste and provide their judgment to avoid temperature decrease and solidification of the liquor.

Figure 49.

Tempering Cocoa Liquor Samples at 55°C

Source: Authors' own elaboration..

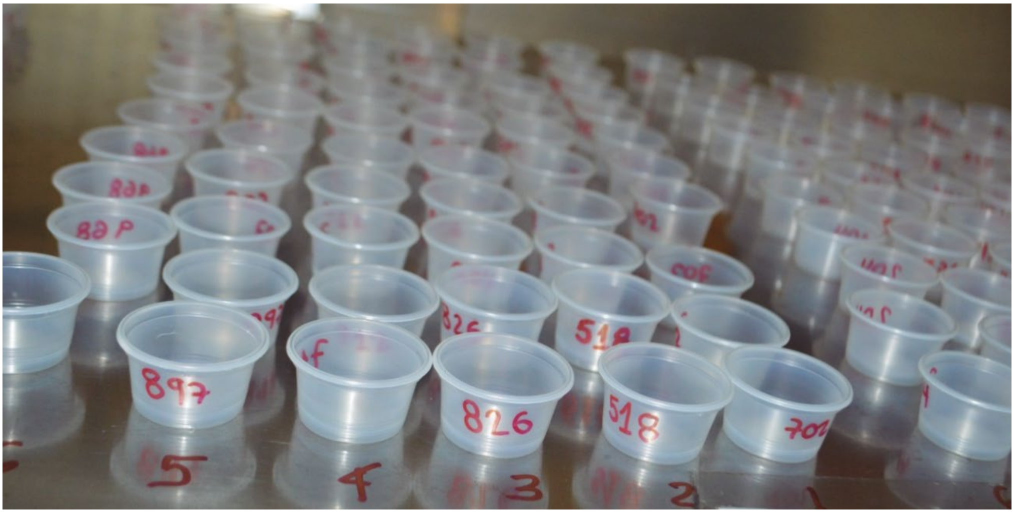
- **Quantity:** The quantity may vary depending on the sample availability and the number of samples the evaluator needs to taste. Generally, an individual sample can be between 5 and 10 grams. There must be enough sample in case an evaluator requests additional sample for testing.
- **Number of samples:** It is important not to present more than five samples to an evaluator in one testing session to avoid sensory fatigue and feelings of fullness.

- **Type of container:** The type of material for serving the sample depends on the sample and the selected sensory test, as some tests require special elements. The containers used for serving cocoa liquor samples should be identical. They should be used only for sensory evaluation tests, not reused, and should not impart any odor or flavor to the sample.

- **Presentation:** All served containers must be properly coded according to the protocol to avoid errors in sample presentation. Samples are presented in 20 ml cups, labeled with codes, and accompanied by a 1 ml spoon to sample without overwhelming the taste receptors (as shown in Figure 50).

Figure 50.

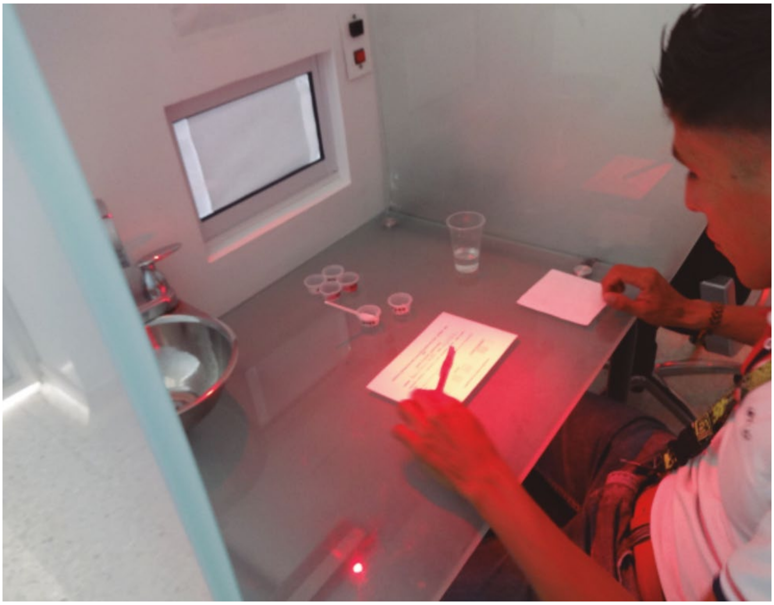
Coding of 20 ml Cups for Sample Presentation to Judges



Source: Authors' own elaboration.

Judges receive the samples to be evaluated in the sensory evaluation laboratory testing booth. The judge should find all necessary elements for evaluation without losing concentration, including samples at ideal temperature and coding conditions, along with the appropriate evaluation forms, a pencil or pen, a glass of water, napkins, and plain soda crackers, if deemed appropriate (as shown in Figure 51).

Figure 51.
Presentation of the Sample in a Sensory Evaluation Booth



Source: Authors' own elaboration (SENA Panel).

5.12 EVALUATION OF COCOA LIQUOR

The sensory evaluation of cocoa liquor is conducted by presenting samples to a trained panel specialized in assessing this product, which serves as the raw material for the chocolate and confectionery industry.

For a panel to evaluate cocoa liquor, specific training in basic cocoa flavors, such as cocoa flavor, astringency, acidity, and bitterness, is required. Additionally, evaluators need to be familiar with specific fine cocoa flavors and aromas such as nutty, fruity, floral, and citrus, as well as those acquired characteristics like raw, green, smoky, moldy, and earthy.

Training judges in specific flavors involves gaining knowledge through the evaluation of a series of samples, which functions as a library of colors, flavors, and aromas. The memorization of these odor and flavor notes (distinctive notes) allows for the identification of fine cocoa flavors and aromas, which have better purchase prices from national and multinational companies.

The precursors of these desired flavors and aromas are developed from their genetic materials and during the fermentation and drying of cocoa beans. Sensory evaluation judges specialized in cocoa liquor understand that during these post-harvest stages, odorant molecules are produced through biochemical processes and transformed into amino acids, small proteins, and reducing sugars. When evaluating a cocoa liquor sample, judges can accurately predict what occurred during these processes based on the substances they perceive when assessing the attributes of the final product (Sukha, 2016).

An attribute is a characteristic of a food that can be perceived through the senses. This characteristic helps define the intensity regarding the persistence of the stimulus. The quality of the attribute refers to the relationship between the traits of interest of a product, and their presence may be favorable or unfavorable at a given moment.

In recent decades, there has been an increase in international demand for cocoa, particularly for genetic materials considered fine in flavor and aroma, which are primarily found in South America. This business has also brought higher standards for the quality of exported cocoa and cocoa liquor, the base for the mass-market chocolate industry in European countries and the United States.

These international demands have led to the implementation of systems to ensure the quality of cocoa in its physical, chemical, and sensory variables. From a sensory perspective, standardization organizations, associations, academia, and government bodies are working together to establish protocols and sensory evaluation laboratories for cocoa liquor (Bolger et al., 2017).

Sensory evaluation of cocoa using the analytical method involves a sensory evaluation panel. A minimum of five or six evaluators trained in the specific cocoa flavors is required to evaluate three to four samples per day. Therefore, it is important that the panel has enough evaluators available. All selected evaluators have the skills to provide a rating on a specified scale they have been trained on and can quantify the flavor and aroma concentrations of an attribute (Vázquez-Ovando et al., 2015).

The particular properties identified as the typical flavor and odor of cocoa liquor include: cocoa flavor, acidity, bitterness, and astringency. Specific traits of certain genetic materials and regional influences on flavor and aroma, such as fruity, floral, and nutty notes, can also be present. Conversely, undesirable flavors and aromas may result from uncontrolled fermentation or contaminants, such as raw or green, smoky, moldy, or earthy (Misnawi et al., 2004).

Sensory analysis is analytical, and therefore, the results of the sensory evaluation panel must be based on rigorous training in concepts and scales from 1 to 10 regarding cocoa liquor attributes. The importance of these results and evaluations, particularly for cocoa liquor, lies in the reproducibility of processes and comparison with other sensory evaluation laboratories using expert panels (Sukha, 2016).

The flavors and aromas of cocoa liquor define the attributes for which genetic materials are valued and determine the quality of the product related to those fine flavors and aromas achieved through good agricultural practices and transformation processes from the bean to cocoa liquor. The basic flavors of cocoa liquor are accentuated or diminished depending on the transformation processes, as shown in the following table:

Table 18.
Basic Flavors for Cocoa Liquor

Basic flavors	Description
Acidic	The acidic flavor in liquors is due to the presence of volatile and non-volatile acids.
Bitter	Strong and bitter flavor, usually due to inadequate fermentation.
Sweet	Produced by the perception of glucose present.
Astringent	Results from high concentrations of substances such as polyphenols and lack of fermentation, causing dry mouth and increased salivation.

Source: Januszewska (2018).

The specific flavors of cocoa liquor arise from biochemical processes during fermentation and roasting of cocoa beans, including molecules such as sugar, amino acids and fatty acids. Table 21: Specific Flavors of Cocoa Liquor describes the acidic substances found in cocoa liquor (Jiménez et al., 2011).

Table 19.
Specific Cocoa Liquor Flavors

Specific flavors	Description
Cocoa	Describes the typical flavor of well-fermented, dried, and roasted cocoa beans. Glutamine with glucose produces a "chocolate" aroma.
Floral	They have floral, almost perfumed flavors. Valine and glucose produce "pungent chocolate" sensory notes.
Fruity	Ripe fruit flavored liquors.
Nutty	It is related to the flavor of almond and nut.

Source: Jiménez et al. (2011).

Microorganisms present during the fermentation process (yeasts, lactic acid bacteria, and acetic acid bacteria) produce metabolites such as ethanol and lactic and acetic acids. These accumulations occur in the cocoa bean and result in a significant decrease in pH to 4.5-5.5. When fermentation ends and drying begins, substances such as acetic acid come out from inside the cocoa bean (Moreira, 2018).

It is important to highlight the significance of citric acid, produced from the fermentation of sugars by microorganisms such as yeast, and especially by fungi from the *Aspergillus* and *Penicillium* genera.

Cocoa beans should maintain a hygroscopic state, which is crucial for preserving the cocoa bean during storage, with a moisture content of 7% to limit the growth of microorganisms such as fungi or bacteria, which can alter the flavor and aroma of the cocoa bean (Bolger et al., 2017).

Cocoa beans can also absorb volatile substances from the environment, which can impart unusual flavors to the cocoa. These substances may come from the use of containers that previously held chemical substances. Volatile compounds produced by combustion can be absorbed by the beans, primarily from wood or wood-based materials (Januszewska, 2018). Table 20 describes the main acquired flavors.

Table 20.

Acquired Flavors

Acquired flavors in cocoa liquor	Description
Mold	Cocoa liqueurs with a moldy flavor. Resulting from fermentation of the beans or improper drying.
Chemical	Cocoa liquors from cocoa beans contaminated with fuel, pesticides, disinfectants or other chemicals.
Unripe/raw	Describes cocoa beans lacking fermentation or roasting.
Smoke	Cocoa liquors contaminated by wood smoke, usually due to artificial drying.

Source: Bolger et al. (2017) and Jiménez et al. (2011).

NTC 3929 of 2009 proposes a scale for rating the intensity of each attribute from 0 to 5. For cocoa, a scale from 0 to 10 has been proposed, detailed in the following table:

Table 21.

Attribute Rating scale

		0	Absent
1	a	2	Low intensity
3	a	5	Medium intensity
6	a	8	High intensity
9	a	10	Very high/strong intensity

Source: Bolger et al. (2017) and Jiménez et al. (2011).

In NTC 3929, the intensity of the attribute and its quality are quantified on a scale of 0 to 10. It is important to note that in some cases, high attribute ratings are inversely related to quality, affecting the final quality of the liquor. Additionally, NTC 3929 regulates the overall rating from 1 to 3. For cocoa, a 0 to 10 scale has been implemented to have the overall picture of the liquor, classify it, and assign it a specific use (Quintana et al., 2018; NTC 3929, 2009).

Table 22 shows a proposed format used in various research projects for the characterization of different cocoa genotypes.

Table 22.

Format for the Evaluation of Specific Cocoa Liquor Attributes

NOMBRE: ______________________ **FECHA** ______________

Las muestras están identificadas con un código de tres dígitos. La escala que se utiliza es de 0 a 10 puntos para medir la INTENSIDAD de cada sabor. La escala para medir la CALIDAD de cada atributo es de 0 a 10 en caso de defectos la valoración es inversa.

Valoración INTENSIDAD atributos.	0 : Ausente	1 a 2: Bajo	3 a 5: Medio	6 a 8: Alto	9 a 10: Muy Alto, Fuerte
Valoración CALIDAD	0 : Mala	1 a 2: Baja	3 a 5: Media	6 a 8: Alta	9 a 10: Excelente

Registro

CODIGO		SABORES BASICOS				SABORES ESPECIFICOS				SABORES ADQUIRIDOS			PERSISTENCIA - SABOR RESIDUAL	CALIFICACIÓN GLOBAL DEL LICOR
		CACAO	ACIDEZ	ASTRINGENTE	AMARGO	FRUTAL	FLORAL	NUEZ		VERDE				De 0 a 10.
	INTENSIDAD ATRIBUTO													
	CALIDAD ATRIBUTO													
	INTENSIDAD ATRIBUTO													
	CALIDAD ATRIBUTO													
	INTENSIDAD ATRIBUTO													
	CALIDAD ATRIBUTO													

Observaciones:-

Source: Authors' own elaboration.

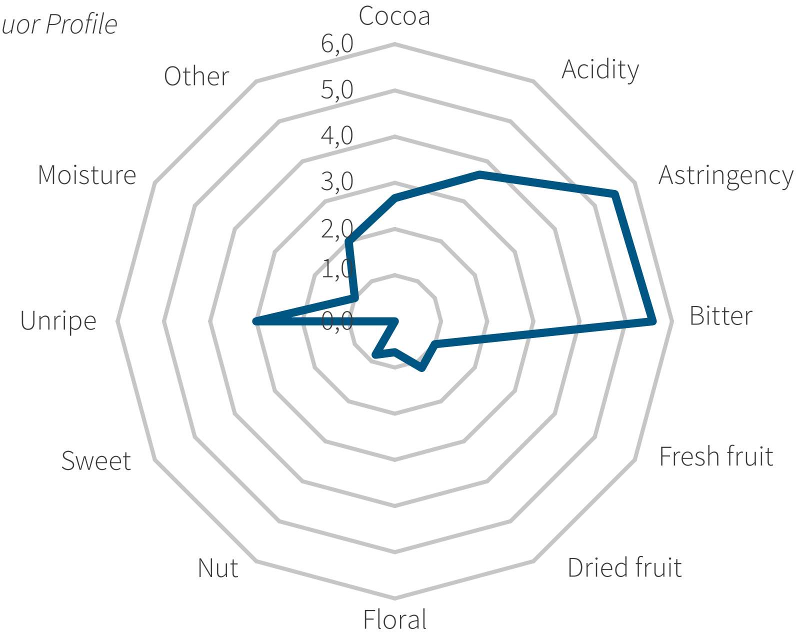
In summary, sensory evaluation determines the attributes of a food product and its permanence during industrial food production or recognition of those patterns in a given crop in a region or country. Therefore, quality refers to good harvest and post-harvest practices, and for cocoa, it means being recognized as fine in flavor and aroma. It also involves cocoa's transformation process into cocoa liquor and chocolate products. This is achieved through a sensory evaluation laboratory, a group of trained evaluators, and good agricultural practices for processing the harvested product.

5.13 SENSORY PROFILE OF COCOA LIQUOR

As previously mentioned, sensory analysis relies on a trained panel, supported by mathematical frameworks and equipped with a laboratory for physical, chemical, and sensory testing. This setup facilitates data analysis, decision-making, and refinement of production processes to enhance competitiveness in the market (Yang and Lee, 2019). Once data is consolidated based on the type of panel, whether by consensus or independently, the results are typically presented using various types of spider or radar graphs, as illustrated in Figure 52.

Figure 52.

Cocoa Liquor Profile

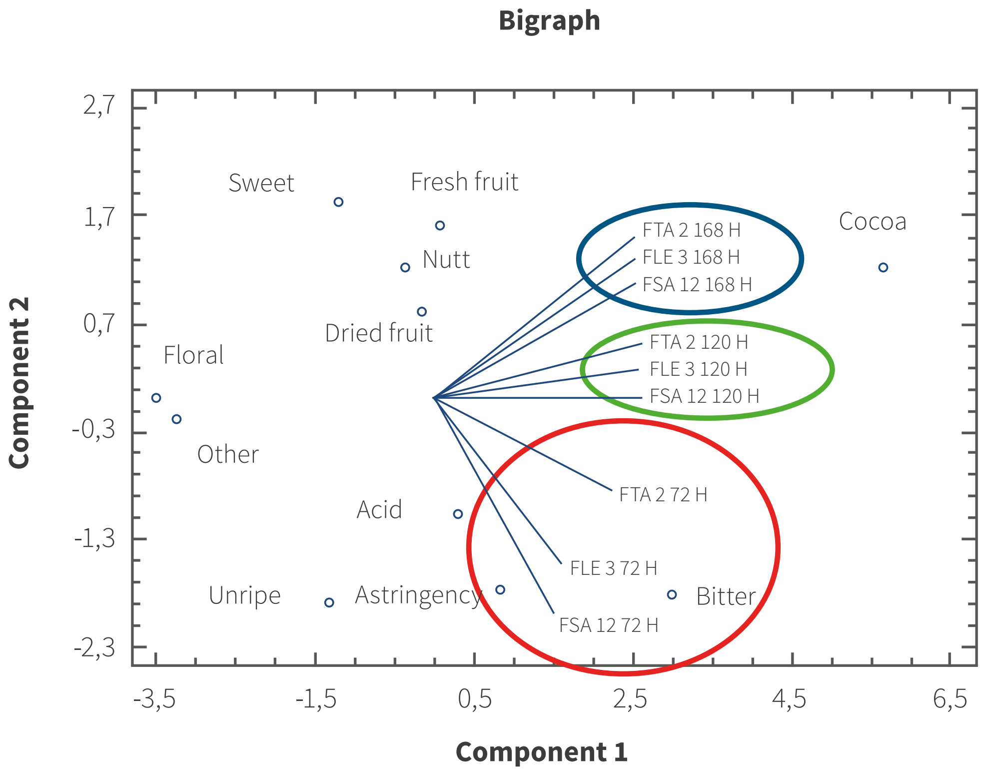


Source: Authors' own elaboration.

The following is an example of how a consolidated analysis of cocoa liquor profiles is submitted once the panel leader processes the results and creates the report. In some cases, when comparing different genotypes with respect to sensory attributes, it is important to rely on multivariate statistical techniques such as Principal Component Analysis (PCA). PCA provides an overall view of each product. Figure 53 illustrates an example of results using PCA:

Figure 53.

Principal Component Analysis of Specific Flavors



Source: Quintana (2018).

When applying these statistical techniques, it becomes possible to discern sample trends and the attributes they approach, allowing for the establishment of trends across sample groups. In the example, cocoa samples with different fermentation times were evaluated, revealing varied behaviors regarding the attributes (Quintana, 2018).

To conclude this chapter, it is important to understand the concepts discussed and the normative references that have been applied in Colombia, which are in line with international standards. This understanding will guide those wishing to establish a well-founded sensory evaluation panel, ensuring repeatable and reproducible evaluations of cocoa liquor with the necessary scientific rigor. This approach aims to shift the general perception that sensory evaluation is purely subjective. The assurance of standardized processes for cocoa liquor production, including handling, serving, facilities, training, training evaluation, report generation, and statistical analysis of results, guarantees quality in the sensory evaluation process.

The assurance of standardized processes for cocoa liquor production, including handling, serving, facilities, training, training evaluation, report generation, and statistical analysis of results, guarantees quality in the sensory evaluation process.

CONCLUSION

In recent years, cocoa cultivation has become an economic alternative for Colombian farming families, offering them a livelihood project with significant social and political implications. It breaks the barriers of poverty and state neglect in rural areas. Cocoa, therefore, has become a crucial engine for the rural economy in Colombia. In 2020, it contributed 64,281 tons of exports to consuming countries, representing 2% of global production, and generated revenues exceeding 11 billion dollars.

Moreover, the expansion of cocoa cultivation has gained social value through national crop substitution programs, providing a financial support option in the countryside through bean exports and contributing to peace-building in post-conflict regions. Cocoa is increasingly becoming part of Colombian entrepreneurship thanks to the domestic processing of cocoa beans and the production of cocoa derivatives such as cocoa liquor, confectionery products, food items, and pharmaceuticals.

However, these circumstances require more research work focusing on the comprehensive quality of cocoa to inform the communities of study findings facilitate the development of these insights. There is a need for conceptual understanding of agricultural practices and product transformation, supported by official regulations, Colombian and international technical guidelines and standards, and their awareness by stakeholders. This is essential for establishing improvement programs across all processes, from cocoa bean cultivation and harvesting to the production of a chocolate bar or other by-products.

It is crucial to emphasize that continued research and study of cocoa's sensory quality could stimulate innovative ideas within small, medium, and large cocoa organizations, leading to more secure entrepreneurial developments. Each topic addressed in this Book highlights and synthesizes aspects generally managed from the perspective of cocoa's comprehensive quality, and with conceptual and normative tools, it will enable readers to relate and establish a quality profile, particularly of the sensory attributes of cocoa, in line with current national and international market demands. This begins with improving cocoa cultivation, which presents new challenges in a field where progress has been made and is being embraced by stakeholders interested in the comprehensive quality of cocoa, thanks to the scientific and technical contributions of universities, research centers, and associations working collaboratively on these aspects.

We are at a pivotal moment as Colombia is fostering an innovative environment conducive to agile and efficient entrepreneurial and productivity processes, supported by public policies, resource availability, knowledge transfer, entrepreneurship education, human talent development, infrastructure availability, and a culture of collaboration. Therefore, with the support of the Universidad Nacional Abierta y a Distancia (UNAD) and its partners, we, the authors, believe this book contributes to the country's goals.

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GLOSSARY

Acidity: One of the five basic tastes detected by the taste buds on either side of the back of the tongue.

Sour: Producing a sensation of acidity.

Almond: Another term for cocoa bean.

Bitter: One of the five basic tastes. It is the most needed of the habits to become an acquired taste and it is because it is perhaps the least pleasant of the five.

Sensory analysis: Examination of the organoleptic properties of a product using the senses.

Qualitative sensory analysis: Description of the nature of the products.

Quantitative sensory analysis: Measurement of the perceived quantity of each attribute in the product.

Sensory analyst: A professional with professional scientific functions, who designs and directs sensory studies, supervises panelists, and analyzes and interprets the obtained data.

Astringency: An astringent taste is a sensation of intense dryness and bitterness experienced in the mouth. Some foods, such as certain unripe fruits like dates and persimmons, have an astringent taste. Some tea infusions also have astringent notes.

Good Agricultural Practices (GAPs): A set of principles, standards, and technical recommendations applicable to the production, processing, and transport of food.

Their aim is to ensure the protection of hygiene, human health, and the environment through ecologically safe, hygienically acceptable, and economically feasible methods.

Cocoa: A tropical tree native to the Amazon rainforest. It has a dense canopy, with fully green adult leaves and white or pink flowers emerging from the stem or branches. The fruit is a drupe (stone fruit) commonly known as a pod. The cocoa tree typically reaches a height of 6 to 20 meters.

Fine aroma cocoa: Almonds with high aromatic potential and other sensory qualities that distinguish them from others (Álvarez and Col, 2007). Fine cocoa has distinctive aroma characteristics and low bitter content.

Cocoa grower: A person who grows or trades cocoa.

Fermentation crate: A wooden container used for fermenting fresh cocoa.

Cauliflorous: Cocoa is cauliflorous because its flowers and fruits develop on the stem and branches of the tree.

Chocolate: A food product made by mixing sugar with two products derived from the processing of cocoa beans.

Consumer: Any person who uses a product.

Questionnaire: A form containing a series of questions designed to obtain information.

Discrimination: The qualitative or quantitative distinction between two or more stimuli.

Embryo: The part of the cocoa bean that gives rise to a new plant.
Sensory fatigue: A form of sensory adaptation characterized by a decrease in sensitivity. Sensory adaptation is a temporary modification of the sensitivity of a sensory organ due to continuous or repeated stimulation.

Fermentation: The enzymatic degradation of sugars in the pulp, resulting in simple products like ethyl alcohol.

Cocoa bean: The healthy and clean seed of the cocoa tree's fruit with biochemical transformations inside, dried, without mucilage, and without shell remains.

Whole bean: A cocoa bean or part of a bean that represents more than 50 % of the total.

Moldy bean: A bean with fungal mycelial growth on the inside.

Slaty bean: A cocoa bean that, when cut longitudinally, has a smooth, compact texture, usually slate-colored or dark.

Purple bean: A cocoa bean with a purple or lilac color inside.

Hedonic: Related to pleasure.

Pod index: The number of pods required to obtain 1 kg of fermented or unfermented and dried cocoa.

Sensory judge: Any person participating in a sensory test.

Cocoa liquor: The product obtained by grinding fermented or unfermented, roasted, and shelled cocoa beans. It is the result of a liquid mass during grinding.

Cocoa butter: A semi-solid product, fatty, at room temperature, white or slightly yellowish. It is obtained from the processing of cocoa beans through mechanical extraction or solvents.

Pod: The indehiscent fruit of the cocoa tree.

Objective method: A method in which the influence of opinions is minimized.

Subjective method: A method in which opinions are taken into account.

Cocoa nibs: Roasted cocoa pieces or chunks obtained after the beans are roasted and shelled.

Note: A lay judge is a person with no particular criteria. An experienced judge has already participated in a sensory test.

Atypical odor: An unusual odor, generally associated with deterioration or transformation of the sample.

Sensory evaluation panel: A group of selected individuals participating in a sensory test.

Perception: Awareness resulting from a simple or complex sensory stimulus.

Pre-selection: Preliminary selection procedure.

Product: A substance for consumption or not, which can be evaluated through sensory analysis.

Paired comparison test: A test in which samples are presented in pairs to compare them based on defined attributes.

Difference test: Any method or test in which samples are compared to determine whether there are differences between them.

Preference test: A test that allows the evaluation of preferences between two or more samples.

Duo-Trio test: A difference test where a reference sample is presented first, followed by two samples, one of which is the reference. The judge must identify the reference sample.

Triangle test: A difference test where three coded samples are presented, two of which are identical. The sensory judge must indicate which sample is different.

Reference: A substance, different from the analyzed product, which defines a property or a specific level of a certain property.

Replicate: Evaluation of a sample more than once.

Panel leader: The person responsible for managing panel activities, recruiting, training, and supervising tasters. This person may also design and direct sensory tests, as well as analyze and interpret data, with the help of one or more panel technicians.

Primary tastes: Tastes produced by diluted aqueous solutions of acidic, bitter, salty, and sweet substances.

Atypical olfactory-gustatory sensation: An unusual olfactory-gustatory sensation, generally associated with sample deterioration or transformation.

Foreign olfactory-gustatory sensation: An olfactory-gustatory sensation unrelated to the product in question.

Sensory: Relating to the sensory organs.

Bias: A systematic error that always occurs in the same direction and can be either positive or negative.

Panel technician: A person responsible for operational functions, assisting the panel leader or sensory analyst with sensory tests, including preparations before the test and activities afterward, such as waste disposal.

Sample control: A product sample used as a comparison element.

Detection threshold: The minimum amount of sensory stimulus required to evoke a sensation. This sensation does not necessarily need to be identified.

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