Sensory attributes of fine flavor cocoa beans and chocolate: A systematic literature review

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ABSTRACT:

Fine flavor cocoa (FFC) is known for its unique flavor and aroma characteristics, which vary by region. However, a comprehensive overview of the common sensory attributes used to describe FFC beans and chocolate is lacking. Therefore, a systematic review was conducted to analyze existing literature and identify the most commonly used sensory attributes to describe FFC beans and chocolate. A systematic search of the Web of Science and Scopus databases was conducted in May 2023, and PRISMA guidelines were followed to ensure transparency and reproducibility. This review summarizes the origins of cocoa and explores their unique flavor profiles, encompassing caramel, fruity, floral, malty, nutty, and spicy notes. While some origins may exhibit similar unique flavors, they are often described using more specific terms. Another main finding is that while differences in sensory attributes are anticipated at each production stage, discrepancies also arise between liquor and chocolate. Interestingly, fine chocolate as the final product does not consistently retain the distinctive flavors found in the liquor. These findings emphasize the need for precise descriptors in sensory evaluation to capture flavor profiles of each origin. As such, the exploration of attributes from bean to bar holds the potential to empower FFC farmers and chocolate producers to effectively maintain quality control.

Keywords: Descriptive analysis, fine aroma, sensory analysis, Theobroma cacao, QDA

Practical Application: -

1. Introduction

Cocoa, a highly cultivated crop grown primarily in equatorial regions, holds significant agricultural importance in multiple countries, such as the Ivory Coast, Ghana, Indonesia, Nigeria, Cameroon, Brazil, Ecuador, the Dominican Republic, and Malaysia (Jahurul et al., 2013). In the realm of processed cocoa, chocolate stands out as one of the most popular foods consumed by people of all ages (Toker et al., 2020). Beckett et al. (2017) report that the market for chocolate products made from specialty cocoas has exhibited strong growth for over two decades. More recently, the premium chocolate market has witnessed a remarkable growth, reaching USD 30.10 billion in 2023 and is projected to soar to USD 46.12 billion by 2028 (Mordor Intelligence, 2023). This upward trend is further driven by the increasing demand for high-quality cocoa and chocolate, fueled by consumer preferences for unique flavors, traceable origins, and ethical production methods (Beg et al., 2017; Gresley & Peron, 2019). Not surprisingly, there is also a corresponding rise in demand by global fine flavor chocolate industries for fine or flavor cocoa (FFC), renowned for its unique sensory attributes and high quality (Afoakwa et al., 2008; Xiao-Wei Qin, 2017).

From a global marketing perspective, cocoa can be classified into two broad categories: bulk or ordinary cocoa and FFC. FFC is purchased at a premium price, often starting at about 20% and sometimes reaching double or even triple the price of bulk cocoa beans due to its unique flavor or color attributes (Beckett et al., 2017). FFC encompasses a range of flavors that emerge as key factors influencing purchase intention and consumer preference (Prete & Samoggia, 2020). These flavors include notes of fruit, floral, herbs, wood, nuts, caramel, and a rich and balanced chocolate base (Afoakwa et al., 2008). According to The International Cocoa Organization (ICCO), there is a slight difference in the definition of fine and flavor cocoa; both are defined to have unique flavors, but fine cocoa is characterized as cocoa that is free of defects, while flavor cocoa is assumed to have little to no defects in flavor. Among the primary cocoa varieties, Criollo, considered the finest, rarest, and most prized variety, possesses aromatic components that impart fruity, flowery, herbal, woody, nutty, and caramel flavors (Castro-Alayo et al., 2019). In contrast, Forastero, the most commonly grown variety, is valued for its basic cocoa flavor but lacks the unique flavor notes found in Criollo (Ríos et al., 2017; Jaimez et al., 2022). Trinitario, a hybrid of Criollo and Forastero, offers a balance between the two and is frequently used in premium chocolate blends (Smulders et al., 2012; Żyżelewicz et al., 2018). ICCO recognizes Criollo and Trinitario as FFC varieties due to their unique flavors. However, the classification of cocoa as FFC is not solely determined by its variety but rather depends on the presence of unique flavors. For instance, Nacional trees in Ecuador, although traditionally categorized as Forastero, have demonstrated the capacity to produce FFC (Kooij, 2013). This exemplifies the importance of understanding the diverse sensory attributes of FFC in describing the wide range of unique flavors found in FFC beans.

The flavor profile of cocoa beans is influenced by a range of factors, including genotype, chemical composition, environmental conditions, cultivation practices, and subsequent processing stages (Kadow, 2020; Munoz et al., 2020). In-depth reviews of these factors have been conducted by Kongor et al. (2016) and Herrera-Rocha et al. (2023). Herrera-Rocha et al. (2023) specifically focused on exploring metagenomics studies and analyzing metabolomics data from different geographical origins, cocoa types, and processing stages. In terms of peptidomics, they concluded that several peptide features could be closely associated with fine flavor notes, providing insights into cocoa flavor development and standardization opportunities. Additionally, (Febrianto et al., 2022; Muñoz et al., 2020) reviewed the formation of flavor during processing. Furthermore, Augusto and Bolini (2022) focused on the conching process, Diaz-Munoz and De Vuyst (2021) and Mota-Gutierrez et al. (2019) explored the impact of fermentation, and Rojas et al. (2022) provided insights into the role of roasting in flavor development.

Another recent review by Castro-Alayo et al. (2019) emphasized the formation of aromatic compound precursors during the fermentation of Criollo and Forastero cocoa. Moreover, Jaimez et al. (2022) conducted a comprehensive review that covered aspects such as origin, genetics, sensory properties, production dynamics, and physiological aspects, but focused solely on the cultivar CCN 51. In their review, (Castro-Alayo et al., 2019; Herrera-Rocha et al., 2023) emphasized that the geographical origin influences the aromatic profile of Criollo cocoa. Expanding on the molecular and sensory aspects of fine flavor, a recent study by Ullrich et al. (2022) delved into the molecular insights of fine flavor properties in dark chocolates. Additionally, addressing flavor profiles and production methodologies, the study by Chetschik et al. (2019) analyzed the flavor profiles of single-origin chocolates and blends through sensomics methodologies. In spite of research studies and reviews on the molecular, chemical, and biological properties of cocoa, only a few have specifically focused on measuring the sensory attributes of FFC from diverse origins and various stages of processing.

In recent years, sensory evaluation has emerged as an indispensable tool for cocoa and chocolate research and development, providing valuable insights into product quality, consumer preferences, and market trends (Harwood & Hayes, 2017). With the increasing demand for premium chocolate products, accurate identification and understanding of sensory attributes in cocoa beans and chocolate have become essential. Sensory evaluation methods offer a scientific approach to product development and quality control, enabling industry professionals to optimize sensory attributes in line with consumer expectations and market trends. As a result, the use of sensory evaluation methods is gaining traction within the cocoa and chocolate industry and is projected to grow in importance (Perez et al., 2020).

Despite the growing interest in FFC and chocolate, the current understanding of the sensory attributes associated with FFC beans and chocolate remains limited. FFC is renowned for its unique flavor and aroma characteristics, which exhibit significant variation depending on specific regions of origin. However, existing literature on the sensory attributes of FFC remains fragmented, with limited focus on exploring specific qualities influenced by factors such as variety, processing, and origin. This fragmented approach has led to a lack of an overview providing a thorough understanding of the most prevalent sensory attributes used to describe FFC beans and chocolate across different origins. Furthermore, variations in terminology and methodology employed in sensory evaluation, combined with the fact that each origin may possess distinct sensory descriptors, have resulted in inconsistencies and discrepancies in obtained results (Escobar et al., 2021).

Therefore, the primary purpose of this systematic review is to comprehensively assess the available literature on the sensory attributes of FFC beans and chocolate, with a specific focus on evaluating the attributes, their consistency and variability. Furthermore, it aims to identify areas where further research is needed and provides a fundamental reference point for future studies in the field of sensory evaluation for FFC. More specifically, the review addressed the following questions: 1) Which sensory analysis methods are used to analyze the sensory properties of FFC and/or chocolate? and 2) What are the most common sensory attributes used to describe FFC and/or chocolate? Importantly, to the best of our knowledge, this review represents the first systematic analysis to elucidate the sensory attributes of FFC and chocolate across diverse origins.

2. Materials and Methods

2.1 Search strategy

A systematic search was conducted on 26 May 2023 to identify eligible articles on the topic of FFC and sensory attributes using two online databases, Web of Science and Scopus. The keywords associated with FFC was developed using references from ICCO and Beckett et al. (2017), while the selection of the sensory-related keywords were aligned with the approach defined by Toker et al. (2020) and Lemarcq et al. (2021).

Boolean searches were performed in both the Scopus database, covering the title, abstract, and keywords, and the Web of Science database, with a specific focus on the topic. The following query was utilized: *(“FFC" OR "Fine Aroma" OR "Flavour Cocoa" OR "Flavor Cocoa" OR "Specialty Cocoa" OR "Premium Cocoa" OR criollo OR trinitario OR nacional OR "Fine Chocolate") AND (descrip* OR profil* OR sensory OR attribute OR organoleptic OR aroma OR flavo* OR taste OR texture OR appearance)*. Furthermore, specific inclusion and exclusion criteria were applied to narrow down the search results to relevant articles (Table 1). The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed to ensure transparency and reproducibility in the search process, as recommended by Page et al. (2021).

2.2 Selection of relevant studies

During the literature search, 4,732 articles were identified (3,132 from Scopus and 1,600 from Web of Science). After being limited to English language research articles, 2,410 articles remained for further consideration. A deduplication process was then conducted, resulting in 1,877 unique articles. These 1,877 articles underwent a comprehensive two-step screening process. In the initial screening, titles and abstracts were evaluated, identifying 194 articles for full screening.

The full texts of these 194 articles were subsequently reviewed based on predefined eligibility criteria outlined in Table 1. As a result, 159 articles were excluded from the review for not meeting the specified inclusion criteria.

Finally, a total of 34 articles that met all the predefined eligibility criteria were included in the systematic review (Figure 1). The articles were primarily excluded due to the lack of relevance to FFC beans or chocolate, focused on subjects unrelated to sensory attributes, or solely highlighted the chemical or physical properties determined through instrumental analysis.

2.3 Data extraction

The data extraction process was carried out by the first author, and the accuracy of the extracted data was verified by the other authors. Any uncertainties or discrepancies that arose during the extraction were resolved through in-depth discussions and consensus among the authors. To ensure a comprehensive understanding of the study characteristics, data extraction sheets were created. These sheets included basic study information (first author, publication year, research topic, and primary research question), sample characteristics (type of FFC and/or chocolate product, origin, and variety), methodological components (sensory evaluation method, evaluated attributes, scale used, number and type of assessors, statistical analysis, and sample preparation), outcome measures (basic and specific sensory modalities) and key findings.

3. Results and Discussion

3.1. General characteristics of included studies

The systematic review covered 34 selected studies conducted from 2008 to 2023 on the sensory attributes of fine flavor cocoa beans and chocolate. The analysis revealed a noticeable upward trend in the number of studies over the years, with the highest number of publications occurring in 2021 and 2022 (Figure 2). Among the specified cocoa origins in the selected studies, Ecuador stood out as the most extensively researched origin, accounting for 8 out of the 34 studies. This aligns with its position as largest producer of FFC (Jano & Mainville, 2007), with over half of the world's production. Following Ecuador, the combined total of studies from Colombia, Brazil, and Peru accounted for almost 50% of the total research.

Interestingly, other cocoa origins recognized as FFC exporting countries based on the international cocoa agreement (ICCO, 2023), such as Grenada (Frauendorfer & Schieberle, 2008), Indonesia (Sari et al., 2022), Venezuela (Portillo et al., 2014), Mexico (Mota-Gutierrez et al., 2021; Vázquez-Ovando et al., 2015) and the Dominican Republic (Korcari et al., 2023; Penella et al., 2023), were each represented by only one study, except for Mexico and the Dominican Republic, of which cocoa varieties were used in two studies. As such, these results suggest potential regions for future research.

A wide range of research topics was explored in the selected studies. To categorize these topics for the review, they were divided into four research topic categories: (1) cocoa bean fermentation and microbiota, (2) sensory evaluation and flavor, (3) cocoa bean varieties and origins, (4) cocoa processing and quality. Notably, cocoa bean fermentation and microbiota were the focus of 17 out of the 34 studies, while sensory evaluation and flavor were the primary subjects in 12 out of the 34 studies. It is noteworthy that although a significant portion of the research concentrated on the fermentation process and its impact on sensory attributes, there was comparatively less emphasis on investigating the influence of FFC varieties and geographical origins on the sensory attributes throughout each production stage, from bean to the end product.

Within the cocoa bean fermentation and microbiota theme, studies delved into microbial diversity during cocoa fermentation, evaluated the fermentation performance, conducted microbial identification, and employed metagenomics to comprehensively dissect and understand the microbial communities actively participating in cocoa fermentation. The sensory evaluation and flavor research category encompassed subtopics including sensory profiling of cocoa genotypes, examination on both chemical and sensory profiles, and exploration of how diverse processing methods impact sensory attributes. Furthermore, the cocoa bean varieties and origins theme delved into subtopics like cocoa bean varietal characterization, the influence of origins and terroir, and genetic determinants of aromas.

3.2. Distribution of cacao varieties studied across product types

The analysis of the selected studies revealed that the Criollo, Nacional and Hybrid varieties were the most extensively studied, comprising more than 50% of the total articles (Figure 3). Additionally, other cocoa varieties, including Trinitario, Arriba Nacional and Native varieties, were also represented in the studies, but to a lesser extent. Furthermore, the analysis showed that certain studies focused on specific cultivars and fine clones, such as ICS 01, ICS 95, ICS 39, TSH 565, and CCN 51 cacao clones (Horta Tellez et al., 2019) or samples consisted of a mixture of two international clones: CCN 51 with ICS-1 and three national ones: FEC 2, FLE 2, and FSV 41 (Barrientos et al., 2019). One study (Pieracci et al., 2021) did not specify the varitiey but was still included in this review as attributes related to fine aroma of FFC were mentioned in the sensory profile of the chocolate samples.

This review identified a total of 14 articles that focused on liquor and an additional 13 articles that examined chocolate forms (Figure 3). Two articles specifically investigated roasted beans, three studies concentrated on unroasted beans, and one research study involved two forms of samples, namely liquor and chocolate. Regarding the cocoa variety, Criollo cocoa beans were prominently used in all stages (3 studies in bean form, one study in liquor and 2 studies in chocolate forms). Trinitario beans, on the other hand, were absent in the bean form but present in liquor and chocolate forms, in two studies each. Nacional beans were exclusively used in the liquor stage (6 studies), while Arriba Nacional beans were solely utilized in the unroasted bean form, showcasing unique characteristics in their raw state. Hybrid beans were exclusively represented in the chocolate form across 6 studies. Native Peruvian beans exhibited relevance across multiple stages, with one study focusing on unroasted beans and one study each in liquor form, as well as research encompassing both liquor and chocolate stages. Specific cultivars and fine clones had limited representation but were primarily present in the liquor stage.

It is important to note that none of the research included in this dataset conducted a comprehensive analysis of all sample types for each cocoa variety. The flavor of chocolate, shaped by post-harvest treatment and processing techniques, plays a pivotal role in consumer acceptance and market demands. Previous research, however, often focused on specific sample forms, lacking a holistic evaluation spanning from bean to bar. Given that FFC is recognized as high-quality cocoa primarily due to its unique flavor profile, the need for comprehensive sensory property control is paramount. This can be achieved, for instance, by implementing bean-to-bar sensory evaluation protocols outlined by the International Standards for the Assessment of Cocoa Quality and Flavor (ISCQF) (Cacao of Excellence, 2023). ISCQF provides guidance for sensory evaluation in assessing the quality and flavor of unroasted cacao beans, cacao mass, and dark chocolate. The primary objective of conducting sensory evaluation of unroasted cacao beans using ISCQF is to perform an initial quality assessment complementing the physical evaluation and aroma profile obtained from whole and cut beans. In cacao mass or chocolate, the focus shifts to flavor attributes, including core attributes expected in every sample, complementary attributes unique to fine cocoa or chocolate, and off-flavors.

Additionally, several reasons underscore the importance of this comprehensive approach. Firstly, the FFC market offers cocoa farmers a range of both monetary and non-monetary benefits, distinguishing it from the bulk cocoa market. Moreover, Rojas et al. (2022) emphasize that understanding the chemical and physical changes during processing, especially the roasting process, is crucial for producing higher-quality cocoa products, thereby supporting the industrialization of fine cocoas. In a similar context, Hinneh et al. (2020) highlight the potential for optimizing processes to yield diverse flavor profiles, even achieving 'fine' flavor from 'bulk' cocoa beans.

3.3 Sensory methods applied in the studies

Sensory evaluation can broadly be classified into two basic categories: objective sensory tests, which center on humans as detection instruments using trained panelists, and affective sensory tests, which focus on hedonic responses of consumers (Drake et al., 2023). Originating in the late 20th century, Sensory Descriptive Analysis (DA) explores both qualitative and quantitative dimensions of human perception (Valentin et al., 2012). Techniques like Flavor Profile Method (Cairncross & Sjostrom, 2004), Texture Profile Method (Brandt et al.,1963), Quantitative Descriptive analysis™-QDA™ (Stone et al., 2008), Spectrum™ method (Meilgaard et al., 1999), Quantitative Flavour Profiling (Meilgaard et al., 1999) and Generic Descriptive Analysis (Lawless and Heymann, 2010) showcase differences approaches of DA.While conventional DA typically requires extensive training for a small panel, alternative approaches have emerged in response to industrial demands for faster and more cost-effective methods over the past two decades, with the rise of so-called novel sensory profiling methods such as check-all-that-apply (CATA), sorting, and flash profiling (Marques et al., 2022; Varela et al., 2012). These methods can be employed with semi-trained assessors or even consumers while still delivering valid, reliable, and quick results for the sensory characterization of food products (Varela et al., 2012).

In Figure 4, the distribution of self-reported sensory analysis methods used in the selected studies is presented. Given the focus of this review on the sensory attributes of FFC beans and chocolate, all studies applied DA although it is noteworthy that about 50% of the total studies did not explicitly specify the applied method. The dataset encompassed 17 studies that explicitly detailed their chosen techniques. Among these, three studies leveraged the Sensory profile method (ISO 13299), while seven studies specifically mentioned QDA™. Additionally, two studies each applied the ISCQF technique and generic DA, while the remaining studies employed various specific techniques. Specifically, the methods used include Temporal Dominance of Sensations (TDS), Check-All-That-Apply (CATA), and a combination of QDA™ with an acceptance test.

Notably, a study conducted by Virgens et al. (2021) stood out for its application of a combined approach involving an objective sensory assessment (QDA) alongside affective sensory evaluation (acceptance test). The findings of this study revealed that attributes such as sweetness/caramel and fruity flavor played a positive role in enhancing the acceptance of chocolate samples. Therefore, the integration of an objective sensory test with a subjective consumer test not only gauges consumer preferences but also provides insights into the reasons behind a consumer's liking for a particular product.

This review highlights that only one study utilized a novel sensory profiling technique, specifically CATA. The limited application of novel sensory profiling techniques in FFC sensory evaluation shows their potential for future research, as these methods offers several advantages over traditional descriptive sensory methods, such as requiring untrained or minimally trained panelists and employing a simpler protocol (Delarue, 2015; Varela & Ares, 2012). Furthermore, the use of temporal method (TDS) was also limited to just one study, highlighting an opportunity for further investigations into how the flavor profile in FFC beans and chocolates evolves over time. Notably, as TDS shifts from scoring intensities to eliciting dominances, it becomes feasible for panelists with limited or even no training (Schlich, 2017).

When considering assessors' perspectives, four distinct categories are based on expertise and training levels: experts, trained assessors, semi-trained assessors, and consumers or untrained assessors (Song et al., 2022). The dataset reveals that 5 out of 34 studies used experts, 22 employed trained assessors, a study utilized semi-trained assessors, three studies employed assessors labeled as consumers or untrained and there were 4 studies with no assessor type information. While most studies align the chosen sensory evaluation method with assessor type, involving expert and trained assessors in DA, some studies present limitations. For instance, as DA typically requires 8 to 12 trained panelists (Lawless & Heymann, 2005), two studies employed only 1 trained assessor for DA and another study used 3 trained assessors (Table 3). Additionally, the study utilizing CATA method involves 6 untrained assessors. CATA typically includes a larger number of untrained assessors compared to traditional descriptive analysis, with common practices ranging from 50 to 100 or more.

From the perspective of how previous studies have determined lexicons for sensory evaluation, it is surprising that 7 out of the 34 studies did not provide information about their sources or references for selecting descriptors in DA. In contrast, 6 studies explicitly mentioned the Cocoa of Excellence Programme by ISCQF as their reference lexicon. These studies contribute to the establishment of a global list of descriptors, promoting shared understanding among researchers, producers, and consumers, regardless of their geographical or cultural backgrounds. Additionally, seven studies utilized lexicon references from previous researc (Sukha et al., 2008;

Burgos et al., 2008; Oliva-Cruz et al., 2021; Afoakwa, E.O., 2016; Yuh, E., 2014) and national standards (Colombian Institute of Technical Standards and Certification, French Agency for Standardization, and USAID 2018) (Table 3). (Table 3). In order to have usefull sensory results, enable replications and advance the understanding of the sensory profile of cocoa liquor and products, it is crucial that studies provide clear sensory descriptors and references such as provided in Das Virgens et al., (2021).

Considering the variation in flavor profiles across different cocoa origins, even within the same variety, the creation of more standardized region-specific lists of descriptors becomes essential. This regional specificity is crucial for comprehending the nuanced aspects of cocoa and its derivatives, which can reflect the terroir and local production practices. While a global list of descriptors is important for standardization and effective communication (Lemarcq et al., 2022), recognizing regional variations is equally vital for capturing the rich diversity within the cocoa industry.

3.4. Variability in Flavor Profiles Across Cocoa Varities And Origins

The majority of the studies suggest that the same variety of cocoa exhibits diverse and unique flavor profiles across different origins (Table 2 and Figure 6). Focusing on Criollo, one of the most extensively researched FFC varieties, it is notable that a common fruity flavor attribute is shared among Criollo varieties from Venezuela, Peru, and Mexico. However, specific differences emerge among these origins. For instance, Criollo from Venezuela and Peru both exhibit a general fruity profile, with common floral undertones. In contrast, Criollo from Mexico showcases orange citrus notes, distinguishing it from the other origins. Additionally, Criollo from the Dominican Republic displays fruity flavors with a unique emphasis on red fruit notes.

Besides the shared fruity attributes, floral flavors are observed in Criollo from both Venezuela and Peru, revealing a common floral characteristic in these origins. Furthermore, nutty flavors are found in Criollo from both Peru and Mexico, with research findings indicating that Criollo cacao from Mexico exhibits a specific and pronounced nutty flavor profile, characterized by hazelnut and peanut notes peanut (Korcari et al., 2023; Mestanza et al., 2022; Mota-Gutierrez et al., 2021; Portillo et al., 2014). Interestingly, alcoholic and caramel flavors are exclusively associated with Criollo from Mexico.

The review by Kongor et al. (2016) and the study by Cevallos-Cevallos et al. (2018) have stated that Criollo cacao primarily exhibits floral, fruity, and woody characteristics without identifying nutty notes from various origins. This underscores the complexity of cocoa flavor, influenced not only by the variety of cocoa but also by soil chemical compositions, age of cocoa trees and post-harvest treatments. Consequently, this review reveals that while some origins may exhibit similar unique flavors, they are often described using more specific terms, or there are certain flavors that can only be found in specific origins, even when the cocoa variety is the same. This highlights the importance of further refining and clarifying sensory descriptors to accurately capture the distinct flavor characteristics of FFC in each origin.

Five out of the 34 selected studies specifically investigated the Trinitario cacao variety, which exhibits a diverse array of flavor notes originating from different regions. Floral notes are prevalent in Trinitario cacao from Indonesia, the Dominican Republic, Colombia, and Ghana. Additionally, another dominant flavor characteristic observed in Trinitario cacao is fruitiness, found in beans from Ghana, Indonesia, and the Dominican Republic. While the selected studies report a common unique fruity flavor for Trinitario cacao, certain origins exhibit more specific descriptors. For instance, Trinitario from the Dominican Republic describes fruity flavors as citrus, dried fruits, red fruits, and yellow fruits, while Trinitario from Indonesia expresses dried and fresh fruits in its flavor profile. The fruity and floral notes present in Trinitario are associated with the presence of esters and alcohols (Calvo et al., 2021). Additionally, Trinitario cacao from regions like Ghana, Colombia, and the Dominican Republic displays nutty notes. Nutty notes that found in Ghana is in line with research by Hinneh et al. (2020) who stated that the Ghanaian and Ivorian chocolates predominantly nutty. Furthermore, Trinitario cacao from Colombia and Indonesia showcases spiciness, which could be explained that even each variety has a unique potential flavor character, growing conditions such as climate, the amount and time of sunshine and rainfall, soil conditions, ripening, time of harvesting, and the time between harvesting and bean fermentation all contribute to variations in the final flavor formation (Afoakwa et al., 2008).

Previous research about the sensory attributes of the Nacional variety is mainly reported by Ecuador and the Dominican Republic. The Nacional variety of cocoa from Ecuador exhibits a diverse range of flavor characteristics, including floral, fruity, nutty, spicy, and malty notes, as well as earthy, herbal, and woody undertones. These flavor profiles align with the literature, which describes Nacional as having distinctive floral flavor notes (Counet et al., 2004; Luna et al., 2002). The fruity notes in the Nacional cocoa from Ecuador also encompass a wide range, including berry, citrus, dried fruits, dark tree fruit, and tropical flavors, including banana. This variety of fruity flavors is consistent with the diversity of cocoa flavor profiles reported by Kongor et al. (2016). The specific fruit flavors observed in Nacional cocoa might be influenced by environmental conditions, post-harvest practices, and the presence of certain flavor precursors, such as volatile compounds formed during fermentation and drying (Taylor & Roberts, 2004). Additionally, the Nacional cocoa from Ecuador exhibits nutty and spicy notes, which can be attributed to the genetic composition of the beans and the interactions between proteins and lipids during fermentation and roasting (Afoakwa et al., 2008). Moreover, Streule et al (2022) has mentioned malty notes in Nacional cocoa from Ecuador, adding another layer of diversity to the flavor profile of the Nacional variety across origins. When comparing Nacional cacao with Criollo and Trinitario varieties, it is evident that Nacional exhibits a diverse and distinct flavor profile. It shares similarities with Trinitario in terms of floral and fruity flavors. However, Nacional cacao sets itself apart with its berry, citrus, dried fruits, and tropical nuances. Additionally, the nutty and spicy undertones found in Nacional further contribute to its unique sensory attributes.

Hybrid cocoa, with its diverse origins, presents a wide array of flavor profiles. From Brazil, a study by Bastos et al. (2019) documented a milky taste, contributing to its unique flavor. While study with origin from Colombia, the hybrid cocoa exhibits floral, fruity, nutty and spicy (Escobar et al., 2021). On the other hand, hybrid cocoa from Ecuador introduces specific floral notes, flowers, orange blossom, and herbal (Papalexandratou et al., 2011). Additionally, Brazil's hybrid cocoa brings a distinct floral of tobacco. The fruity flavor is a common thread found in hybrid cocoa from all origins, however in the Ivory Coast, this fruity taste encompasses both dried and fresh fruit characteristics. Moving on to Columbia's hybrid cocoa, it delivers nutty taste, further enriching the diversity of flavors. Spiciness is another noteworthy attribute in hybrid cocoa, primarily observed in the offerings from the Ivory Coast and Colombia. Lastly, hybrid cocoa from the Ivory Coast also presented vegetable flavor, setting it apart with its distinct and engaging taste profile (Bastos et al., 2019; Kouassi et al., 2022; Miguel et al., 2017; Escobar et al., 2021; Virgens et al., 2021; Papalexandratou et al., 2011).

When comparing the Hybrid cacao varieties, it is evident that certain flavor attributes are shared among them. For instance, Hybrid cacao from the Ivory Coast, Colombia, and Ecuador exhibits floral flavors, which are reminiscent of Criollo cacao (Cevallos-Cevallos et al., 2018).

Additionally, the fruity flavors found in Hybrid cacao from Ecuador, Brazil, Colombia, and the Ivory Coast are consistent with those observed in Trinitario (Calvo et al., 2021). However, each Hybrid cacao variety also presents unique flavor profiles specific to its origin. For example, Brazilian Hybrid cacao stands out with its milky and woody tobacco flavors, while Ecuadorian Hybrid cacao introduces herbal notes. These differences highlight the influence cocoa genotypes used in hybridization and environmental factors on the flavor profile of Hybrid cacao. For example, cocoa grown at higher altitudes might experience cooler temperatures, leading to slower fermentation and potentially have different flavor profile.

Additionally, aside from the unique flavor that serves as a marker for FFC, astringency is also influenced by cocoa variety. In contrast to the Criollo and Trinitario (FFC), Forastero (bulk cocoa) exhibits a more bitter and astringent taste, as demonstrated by the findings of Castro-Alayo et al. (2019). Various studies from different countries further compare the flavor profiles between bulk and FFC. Research on Ecuadorian cocoa (Papalexandratou et al., 2011; Rottiers et al., 2019) underscores that FFC liquors were richer in volatiles than the bulk liquor, with FFC showcasing fruity and floral notes, while bulk samples present astringency, impurity, and bitterness. Similarly, investigations in Indonesia (Sari et al., 2022) and Ghana (Sukha et al., 2008) indicate that bulk cocoa tends to yield beans with a lower aromatic potential, whereas FFC is predominantly characterized by fresh fruit, floral, woody, and nutty aromas. Notably, divergent findings from Mexico by Mota-Gutierrez et al. (2021) emphasize that only the "rancid" attribute was significantly more prevalent in fermented Criollo than in Forastero beans after 72 hours of fermentation.

The Fine Cultivars demonstrate a flavor profile that encompasses floral and fruity notes, along with nutty undertones. However, without specified origins in the data, direct comparisons and a deeper understanding of their unique flavor qualities are challenging. On the other hand, among the Fine Clones variety, the mix from Colombia stands out with its captivating blend of creamy, floral, fruity, and spicy elements. This variety introduces milky and fatty notes, alongside woody and tobacco flavors, and exhibits nutty and spicy characteristics, including the infusion of hot spices (Barrientos et al., 2019; Fernández-Niño et al., 2021).

3.5. Sensory attributes measured across different product types

Researchers have explored various sensory attributes across different product types, often combining aroma with taste, taste with flavor, or even intertwining texture with aroma, taste, and flavor in specific sample types, each with different percentages (Figure 5). Among these sensory aspects, flavor emerged as the predominant focus in application studies, with 26 out of 34 studies delving into this aspect. Within this group, only one study concentrated solely on flavor, while the remaining 25 studies investigated the intricate relationships between flavor and other sensory modalities. Furthermore, an intriguing finding from one of the selected studies (Mejia et al., 2021), which compared sensory profiles in liquor and chocolate (cacao percentage of 52% and 70%), revealed that floral notes were detected in cocoa liquor but not in the chocolate. Another discovery by Frauendorfer, F., & Schieberle, P. (2008), comparing the aroma of unroasted and roasted beans, showed that although the same compounds were present in both unroasted and roasted beans, their intensities varied significantly. For instance, the notes of rancid and sour were more pronounced in unroasted beans, while malty, caramel-like, and sweaty attributes were heightened in roasted seeds.

In the fine or flavor cocoa market segment, the unique flavor, along with physical characteristics, not only enhances the overall quality of cocoa but also influences the premium price it commands (Sukha and Umaharan, 2017). The cocoa variety primarily impacts the flavor, whereas other sensory modalities, particularly the texture (hardness) of chocolate, are more significantly influenced by various factors such as formulation, manufacturing techniques, tempering, polymorphism (fat stability), and cooling temperature control (Afoakwa et al., 2007).

Moreover, a study by Virgens et al. (2021) has emphasized the correlation between appearance, texture attributes, and hedonic and acceptance responses. However, concerning sensory modalities, only 5 out of 13 studies evaluating sensory properties in fine chocolate included measurements of texture attributes (Table 3). Although fat content and fatty acids profile directly affect texture, viscosity and melting behavior (Afoakwa, 2010), a recent study by Melo et al. (2020) concludes that cocoa variety influences the composition of fatty acids. Therefore, this literature review underscores the necessity for further research that encompasses a comprehensive range of sensory modalities beyond flavor, such as texture. Notably, despite the ISCQF having protocols for unroasted cocoa beans' sensory evaluation, only four studies have conducted sensory evaluations on unroasted cocoa beans. To ensure comprehensive assessments for unroasted beans and liquor, sensory evaluation should adhere to the guidelines established by ISCQF.

3.6. Research gaps and future perspectives

The present review emphasizes the need for further research in several key areas to advance our understanding of sensory attributes in FFC bean and chocolate. These areas include adapting sensory descriptors to specific cocoa origins, comparing flavor attributes across various origins or regions within a country, exploring novel descriptive methods as an alternative sensory profiling for FFC and comprehensive sensory research from bean to bar.

The review of 34 studies identified unique and specific flavor notes, such as citrus orange, red fruits, fresh fruits, yellow fruits, banana, hazelnut, peanut, and walnut, which are part of fruity and nutty notes and can vary significantly depending on the cocoa origin. While there are already sensory descriptors for FFC, highlighting distinct aromas and flavors such as fruity, floral, herbal, and nutty notes, the cocoa industry still lacks globally harmonized quality standards (Wattnem et al., 2022). This review serves as a foundational exploration and implies that international sensory attributes may not comprehensively capture the distinct characteristics of cocoa beans cultivated in specific regions. To address this limitation, future research should explore sensory attributes tailored to the local varieties and origins of cocoa beans. Such research endeavors aim to deepen the understanding of flavor variations and provide more reliable guidance for cocoa producers in specific regions or countries. Moreover, it is essential to establish clear definitions and standardized classifications for cocoa bean characteristics in future research, ensuring accurate and reliable comparisons across various cocoa origins and varieties.

Conducting further research to determine the impact of different origins on comprehensive sensory modalities is also intriguing. This review revealed that cocoa beans from various origins exhibit distinct flavor profiles due to variations in soil composition, climate, and cultivation practices. Understanding these differences might help in distinguishing the quality and characteristics of cocoa beans, allowing producers to create unique and desirable products. As FFC is a competitive market, and differentiation is key, highlighting the origin-specific sensory attributes will serve as a marketing strategy, setting products apart and attracting consumers interested in exploring the nuances of cocoa origins.

In terms of sensory evaluation methods, it is crucial to explore novel sensory profiling methods as an alternative to traditional methods. Among the 34 studies reviewed, only one study applied such novel sensory profiling method. However, considering the potential benefits of these methods in terms of efficiency and accessibility, such as reducing training periods and addressing issues with panel validation, further investigation into their feasibility and validity for FFC sensory analysis is warranted (Varela & Ares, 2012). While various novel sensory profiling methods have been employed in the evaluation of chocolate and chocolate products in the past (Orden et al., 2021; Reinbach et al., 2014; Waehrens et al., 2016), their application has not been extensively explored within the realm of FFC bean and chocolate. By addressing challenges associated with traditional descriptive methods, these novel sensory profiling methods have the potential to significantly enhance the accessibility of sensory evaluations in the field of FFC and chocolate research.

Monitoring sensory attributes from bean to bar is not only crucial for ensuring consistent quality control throughout the entire production process but also empowers FFC farmers and bean-to-bar producers to maintain desired flavor profiles and meet consumer expectations. In addition to this, the systematic literature review has highlighted a significant research gap within the domain of FFC and chocolate, specifically the absence of studies tracking sensory attributes from bean to bar. A potential explanation for this gap could be the limitations in facilities or collaborations, particularly between industry and academia or research institutions (Sukha et al., 2008). Furthermore, the absence of globally harmonized quality standards (Lemarcq et al., 2022; Wattnem et al., 2022) may contribute to this gap.

Another area that requires attention is the holistic assessment of FFC sensory attributes. Beyond aroma and flavor, future studies should expand their measurements to include all sensory modalities, such as appearance, texture, and taste. While several studies have examined aroma and flavor in either cocoa liquor or chocolate, only 2 studies have addressed all sensory modalities. By considering all sensory modalities, researchers will obtain a more comprehensive understanding of cocoa quality and its variations across different origins and varieties. The adoption of sensory evaluation practices from bean to bar in accordance with ISCQF would not only enable cocoa farmers and producers to refine their processes and optimize post-harvest practices but also unlock the full flavor potential of their cocoa. Additionally, participating in the FFC market can offer significant economic and social benefits for cocoa farmers compared to the bulk market (Ríos et al., 2017). Therefore, it is recommended that future research should explore sensory attributes in FFC from the bean-to-bar perspective, as this knowledge can be utilized as a standard to increase FFC producer competitiveness and ensure higher participation in the FFC market.

4. Conclusion

This paper presents the first systematic literature review investigating the sensory attributes of FFC in various forms, including beans, liquor, and chocolate. The review explored various sensory evaluation methods, with traditional descriptive methods being the prevailing approach. Through the analysis of 34 studies, all conducted between 2008 and 2023, valuable insights have been gained regarding the diverse flavor profiles exhibited by cocoa origins and varieties, encompassing fruity, floral, nutty, spicy, and other distinct subcategories of flavor notes. The review identifies that while the same cacao variety may share similar flavor notes among varieties from different regions, there are specific flavors that are unique to certain origins. For example, caramel notes are reported only in Criollo varieties from Mexico, and nutty notes are found in Criollo from Mexico and Peru. Additionally, the review highlights origin-specific flavor attributes. For instance, while Trinitario varieties from Colombia share a general fruity note, those from the Dominican Republic and Indonesia introduce more specific fruity notes, including fresh, red, and yellow fruits. This systematic review underscores the significance of origin-specific flavors and the importance of using specific descriptors in sensory evaluation to capture the full range of unique flavor profiles specific to each origin.

*The **Author Contributions** section is automatically generated from CRediT information entered in the submission form—do not include in your text. See an explanation here.*

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Conflicts of Interest

There is no conflict of interest in this publication.

Data Availability: -

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Table 1. Inclusion and exclusion criteria used for article selection.

Inclusion criteria	Exclusion criteria
• FFC (bean, liquor or chocolate produced from FFC) are the primary or part of the study • Studies must report sensory attributes as a primary aim or as a component of the study • Studies conducted on human subjects • Studies published in scientific journals • Studies that use descriptive sensory analysis or consumer sensory testing to evaluate the sensory attributes of FFC or chocolate made from FFC • Studies based on primary data • Studies published in English	• Not including descriptive sensory attributes • Focus only on properties which measured by laboratory instrument (not by human) • Studies that only report on the sensory attributes of non-FFC or non-chocolate products • Studies that only report on the chemical or physical properties of cocoa or chocolate, without any sensory evaluation • Non-peer-reviewed publications • Reviews

Table 2. Flavor variations and trends in different cacao varieties

Variety	Unique Flavors	Flavor Subcategories	Description (ISCQF)	Origin	Reference
Criollo	Alcoholic		-	Mexico	Portillo et al. (2014) Mestanza et al. (2022) Mota-Gutierrez et al. (2021) Korcari et al. (2023)
	Caramel		Aromas reminiscent of caramel, brown sugar and panela (unrefined cane sugar)	Mexico	
	Floral	Floral	Total floral is composed of Orange blossom and Flowers (jasmine, honeysuckle, rose, lilac, lilies, etc.)	Venezuela	
		Floral		Peru	
	Fruity	Fruity	Total fresh fruit is composed of the following sub-attributes: · Berry · Citrus · Dark · Yellow/ orange/ white flesh · Tropical	Venezuela	
		Fruity		Peru	
		Citrus: Orange	Orange	Mexico	
		Red fruits	-	Dominican Republic	
	Nutty	Nutty	Total nutty is composed of the following sub-attributes: · Nutty – nut flesh · Nutty – nut skins	Mexico	
		Nutty		Peru	
		Hazelnut	Hazelnut	Mexico	
		Peanut	-	Mexico	
Trinitario	Floral	Floral	Total floral is composed of Orange blossom and Flowers (jasmine, honeysuckle, rose,	Indonesia	Sukha et al. (2008) Calvo et al.
		Floral		Dominican Republic	
		Floral		Colombia	

	Floral	lilac, lilies, etc.)	Colombia	(2021)
	Floral		Ghana	Santander et al.
	Woody	Total woody is composed of the following sub-attributes: · Light wood · Dark wood · Resin	Indonesia	(2021)
	Woody		Dominican Republic	Sari et al. (2022) Penella et al. (2023)
Fruity	Fruity	Total fresh fruit is composed of the following sub-attributes: · Berry · Citrus · Dark · Yellow/ orange/ white flesh · Tropical	Ghana	
	Fruity		Colombia	
	Fruity		Colombia	
	Citrus	Orange, lemon, lime, grapefruit or generic sensation of citrus-like fruit.	Dominican Republic	
	Dried	Dried apricot, banana, yellow raisin, fig that has undergone an un sulphured drying process	Dominican Republic	
	Dried		Indonesia	
	Fresh fruits	Total fresh fruit is composed of the following sub-attributes: · Berry · Citrus · Dark · Yellow/ orange/ white flesh · Tropical	Indonesia	
	Red fruits	-	Dominican Republic	
	Yellow fruits	Apricot, peach, pear, banana.	Dominican Republic	

	Malty		-	Colombia	
	Nutty	Nutty	Total nutty is composed of the following sub-attributes: · Nutty – nut flesh · Nutty – nut skins	Ghana	
		Nutty		Dominican Republic	
		Nutty		Colombia	
		Nutty		Colombia	
		Nutty		Indonesia	
	Spicy	Spicy	Total spice is composed of the following sub-attributes: · Spices · Tobacco · Savoury/Umami	Indonesia	
		Spicy		Dominican Republic	
	Winey		-	Dominican Republic	
Nacional	Floral	Floral	Total floral is composed of Orange blossom and Flowers (jasmine, honeysuckle, rose, lilac, lilies, etc.)	Ecuador	Rottiers et al. (2019) Colonges et al. (2022) Streule et al. (2022) Colonges et al. (2022) Penella et al. (2023)
		Floral		Ecuador	
		Earthy	Smell of dampness rising from soil after rain.	Dominican Republic	
		Earthy		Ecuador	
		Earthy		Ecuador	
		Flower	Jasmine, honeysuckle, rose, lilac, lilies, etc	Ecuador	
		Herbal	Hay, straw or herbal / dried green, herbs like thyme and rosemary.	Ecuador	
		Herbal		Ecuador	
		Vegetal: Grassy	Freshly cut grass, young green leaves.	Ecuador	
		Woody	Total woody is composed of the following sub-attributes: · Light wood · Dark wood · Resin	Ecuador	
	Fruity	Berry	Red or black currant, strawberry, raspberry,	Ecuador	
		Berry		Ecuador	

			blackberry, acai berry		
		Citrus	Orange, lemon, lime, grapefruit or generic sensation of citrus-like fruit.	Ecuador	
		Citrus		Ecuador	
		Citrus		Ecuador	
		Dried	Dried apricot, banana, yellow raisin, fig that has undergone an un sulphured drying process.	Ecuador	
		Dried		Ecuador	
		Dried		Ecuador	
		Dark tree fruit	Cherry, plum.	Ecuador	
		Tropical	Passion fruit, pineapple, mango or soursop.	Ecuador	
		Tropical		Ecuador	
		Tropical		Ecuador	
		Tropical: Banana	-	Ecuador	
	Malty		-	Ecuador	
	Nutty	Nutty	Total nutty is composed of the following sub-attributes: · Nutty – nut flesh · Nutty – nut skins	Ecuador	
		Nutty		Ecuador	
		Nutty		Ecuador	
	Spicy	Spicy	Total spice is composed of the following sub-attributes: · Spices · Tobacco · Savoury/Umami	Ecuador	
		Hot spices	-	Ecuador	
		Savory	Sodium glutamate, umami.	Ecuador	
Hybrid	Dairy/Milk		-	Brazil	Papalexandratou et al. (2011) Miguel et al. (2017) Bastos et al. (2019) Escobar et al.
	Floral	Floral	Total floral is composed of Orange blossom and Flowers (jasmine, honeysuckle, rose, lilac, lilies, etc.)	Ivory coast	
		Floral		Colombia	
		Flower	Jasmine, honeysuckle, rose, lilac, lilies, etc	Ecuador	

	Orange Blossom	Orange blossom flavour	Ecuador	(2021) Virgens et al. (2021) Kouassi et al. (2022)
	Herbal	Hay, straw or herbal / dried green, herbs like thyme and rosemary.	Ecuador	
	Woody: tobacco	Dried tobacco leaves	Brazil	
Fruity	Fruity	Total fresh fruit is composed of the following sub-attributes: · Berry · Citrus · Dark · Yellow/ orange/ white flesh · Tropical	Ecuador	
	Fruity		Brazil	
	Fruity		Brazil	
	Fruity		Colombia	
	Fruity		Brazil	
	Dried	Dried apricot, banana, yellow raisin, fig that has undergone an un sulphured drying process.	Ivory coast	
	Fresh	Total fresh fruit is composed of the following sub-attributes: · Berry · Citrus · Dark · Yellow/ orange/ white flesh · Tropical	Ivory coast	
Nutty	Nutty	Total nutty is composed of the following sub-attributes: · Nutty – nut flesh · Nutty – nut skins	Colombia	
Spicy	Spicy	Total spice is composed of the following sub-attributes:	Ivory coast	
	Spicy		Colombia	

			· Spices · Tobacco · Savoury/Umami		
	Vegetable		-	Ivory coast	
Native from Peru	Buttery		-	Peru	Mejía et al. (2021) Michel et al. (2021) Oliva-Cruz et al. (2022)
	Caramel		Aromas reminiscent of caramel, brown sugar and panela (unrefined cane sugar)	Peru	
	Floral	Floral	Total floral is composed of Orange blossom and Flowers (jasmine, honeysuckle, rose, lilac, lilies, etc.)	Peru	
		Floral		Peru	
		Floral		Peru	
	Fruity	Fruity	Total fresh fruit is composed of the following sub-attributes: · Berry · Citrus · Dark · Yellow/ orange/ white flesh · Tropical	Peru	
		Fruity		Peru	
		Fruity		Peru	
	Nutty	Nutty	Total nutty is composed of the following sub-attributes: · Nutty – nut flesh · Nutty – nut skins	Peru	
		Nutty		Peru	
Native from Nicaragua	Floral	Floral	Total floral is composed of Orange blossom and Flowers (jasmine, honeysuckle, rose, lilac, lilies, etc.)	Nicaragua	Papalexandratou et al. (2019)
	Fruity	Fruity	-	Nicaragua	
	Nutty	Nutty	Total nutty is composed of the following sub-attributes: · Nutty – nut flesh · Nutty – nut skins	Nicaragua	

Fine Cultivars	Floral	Floral	Total floral is composed of Orange blossom and Flowers (jasmine, honeysuckle, rose, lilac, lilies, etc.)	N.I	Sukha et al. (2017)
	Fruity	Fruity	Total fresh fruit is composed of the following sub-attributes: · Berry · Citrus · Dark · Yellow/ orange/ white flesh · Tropical	N.I	
	Nutty	Nutty	Total nutty is composed of the following sub-attributes: · Nutty – nut flesh · Nutty – nut skins	N.I	
Mix of Fine Clones	Dairy/Milk		-	Colombia	Barrientos et al. (2019) Fernández-Niño et al. (2021)
	Fatty		-	Colombia	
	Floral	Floral	Total floral is composed of Orange blossom and Flowers (jasmine, honeysuckle, rose, lilac, lilies, etc.)	Colombia	
		Floral		Colombia	
		Woody	Total woody is composed of the following sub-attributes: · Light wood · Dark wood · Resin	Colombia	
		Woody: tobacco	Dried tobacco leaves	Colombia	
	Fruity	Fruity	Total fresh fruit is composed of the following sub-attributes: · Berry	Colombia	
		Fruity		Colombia	

			· Citrus · Dark · Yellow/ orange/ white flesh · Tropical		
	Malty		-	Colombia	
	Nutty	Nutty	Total nutty is composed of the following sub-attributes: · Nutty – nut flesh · Nutty – nut skins	Colombia	
		Nutty		Colombia	
	Spicy	Spicy	Total spice is composed of the following sub-attributes: · Spices · Tobacco · Savoury/Umami	Colombia	
		Hot spices	-	Colombia	
Fine Clones	Floral	Floral	Total floral is composed of Orange blossom and Flowers (jasmine, honeysuckle, rose, lilac, lilies, etc.)	Colombia	Horta-Téllez et al. (2019)
	Fruity	Fruity	-	Colombia	
	Nutty	Walnut	Walnut	Colombia	

Table 3. Overview of sensory methods applied for FFC and Chocolates

No	Sensory evaluation method	Lexicon	Sensory modalities	Assessor(s)	Bean variety	Origin	Product Type	Reference
1	Unspecified DA	Assessors' generated vocabulary	Aroma	10 experts	Criollo	Grenada	Bean (Unroasted) Bean (Roasted)	Frauendorfer, F., & Schieberle, P. (2008)
2	Unspecified DA	NS	Taste Flavor	8 trained	Hybrid	Ecuador	Chocolate	Papalexandratou et al., (2011)
3	Unspecified DA	NS	Aroma Taste Flavor Global quality	11 experts	Criollo	Venezuela	Chocolate	Portillo et al., (2014)
4	Unspecified DA	Sukha et al., (2008)	Taste Flavor	6 trained	Cultivars	NS	Liquor	Sukha and Umaharan, (2017)
5	Unspecified DA	Assessors' generated vocabulary	Aroma Texture Taste Flavor	5 experts	Fine clones (mixture)	Colombia	Bean (Unroasted)	Barrientos et al., (2019)

6	Unspecified DA	Colombian Institute of Technical Standards and Certification	Taste Flavor	NS	Fine clones	Colombia	Liquor	Horta-Téllez et al., (2019)
7	Unspecified DA	Cocoa of Excellence Program Glossary	Taste Flavor	6 trained	Native (Nicaragua)	Nicaragua	Liquor	Papalexandratou et al., (2019)
8	Unspecified DA	AFNOR NF ISO 11035	Aroma Taste	8–15 experts	NS	NS	Chocolate	Adenet et al., (2020)
9	Unspecified DA	NS	Taste Flavor	6 trained	Fine clones (mixture)	Colombia	Liquor	Fernández-Niño et al., (2021)
10	Unspecified DA	ISCQF (2020)	Aroma	1 expert	Nacional	Ecuador	Liquor	Colonges et al., (2022)
11	Unspecified DA	Assessors' generated vocabulary	Taste Flavor	5 trained	Native (Peru)	Peru	Chocolate	Michel et al., (2021)
12	Unspecified DA	ISCQF (2020)	Taste Flavor	NS	Nacional	Ecuador	Liquor	Colonges et al., (2022)
13	Unspecified DA	NS	Aroma Taste Flavor Global Quality	12 trained	Hybrid	Ivory Coast	Chocolate	Kouassi et al., (2022)
14	Unspecified DA	Oliva-Cruz et al. (2021)	Taste Flavor	NS	Native (Peru)	Peru	Bean (Unroasted)	Oliva-Cruz et al., (2022)
15	Unspecified DA	USAID (2018)	Taste Flavor	9 trained	Criollo	Peru	Liquor	Mestanza et al., (2022)

16	Unspecified DA	ICCRI and Guittard Chocolate Company	Appearance Taste Aroma Flavor Global Quality	3 trained	Trinitario	Indonesia	Liquor	Sari et al., (2022)
17	Unspecified DA	NS	Taste Flavor	13 trained	Trinitario	Dominican Republic	chocolate	Penella et al., (2023)
18	QDA™	Burgos et al., (2008)	Aroma Taste	60 consumers	Arriba Nacional	Ecuador	Bean (Unroasted)	Mihai et al., (2022)
19	QDA™	Assessors' generated vocabulary	Taste Flavor	6 trained	Trinitario	Ghana	Liquor	Sukha et al., (2008)
20	QDA™	Assessors' generated vocabulary	Aroma	8 trained	Criollo	Mexico	Bean (Roasted)	Vázquez-Ovando et al., (2015)
21	QDA™	Cocoa of Excellence Program Glossary	Aroma Taste Flavor	8 semi-trained	Native (Peru)	Peru	1. Chocolate 2. Liquor	Mejía et al., (2021)
22	QDA™	NS	Taste Flavor	7 trained	NS	Colombia	Liquor	Calvo et al., (2021)
23	QDA™	NS	Aroma Taste	5 trained	Criollo	Mexico	Bean (Roasted)	Mota-Gutierrez et al., (2021)

24	QDA™	Assessors' generated vocabulary	Aroma Texture Taste Flavor	7 trained	Hybrid	Brazil	Chocolate	Bastos et al., (2019)
25	Sensory profile method (ISO 13299)	Assessors' generated vocabulary	Aroma Taste Flavor	9 trained	Trinitario	Colombia	Chocolate	Santander et al., (2021)
26	Sensory profile method (ISO 13299)	Assessors' generated vocabulary	Aroma Taste Flavor Global quality	8 trained	Hybrid	Colombia	Chocolate	Escobar et al., (2021)
27	Sensory profile method (ISO 13299)	Assessors' generated vocabulary	Appearance Aroma Texture Taste Flavor	10 trained	Criollo	Dominican Republic	Chocolate	Korcari et al., (2023)
28	Generic DA	Assessors' generated vocabulary	Aroma Taste	10 trained	Nacional	Ecuador	Liquor	Streule et al., (2022)
29	Generic DA	Assessors' generated vocabulary based upon Cocoa of Excellence Program Glossary	Taste Flavor	12 trained	Nacional	Ecuador	Liquor	Rottiers et al., (2019)

		(with consensus assessors' modifications)						
30	TDS	Assessors' generated vocabulary	Taste Flavor	10 trained	Hybrid	Brazil	Chocolate	Pedrozo Miguel et al., (2017)
31	CATA	Modified based on previous reports [Afoakwa, E.O., 2016; Yuh, E., 2014]	Appearance Aroma Texture Taste	6 untrain ed	NS	NS	Chocolate	Pieracci et al., (2021)
32	ISCQF	Cocoa of Excellence Program Glossary	Flavor	1 trained	Nacional	Ecuador	Liquor	Colonges et al., (2022)
33	ISCQF	Cocoa of Excellence Program Glossary	Taste Flavor	NS	Nacional	Ecuador	Liquor	Colonges et al., (2022)

34	Combination (QDA + Acceptance test)	Assessors' generated vocabulary	QDA: Appearance Aroma Texture Taste Flavor Acceptance test: Appearance Aroma Flavour Texture Overall liking	QDA: 12 trained Acceptance test: 100 consumers	Hybrid	Brazil	Chocolate	Das Virgens et al., (2021)

CATA: Check-All-That-Apply; TDS: Temporal Dominance of Sensations; QDA: Quantitative Descriptive Analysis; ISCQF: International Standards for the Assessment of Cocoa Quality and Flavour; NS: Not specified

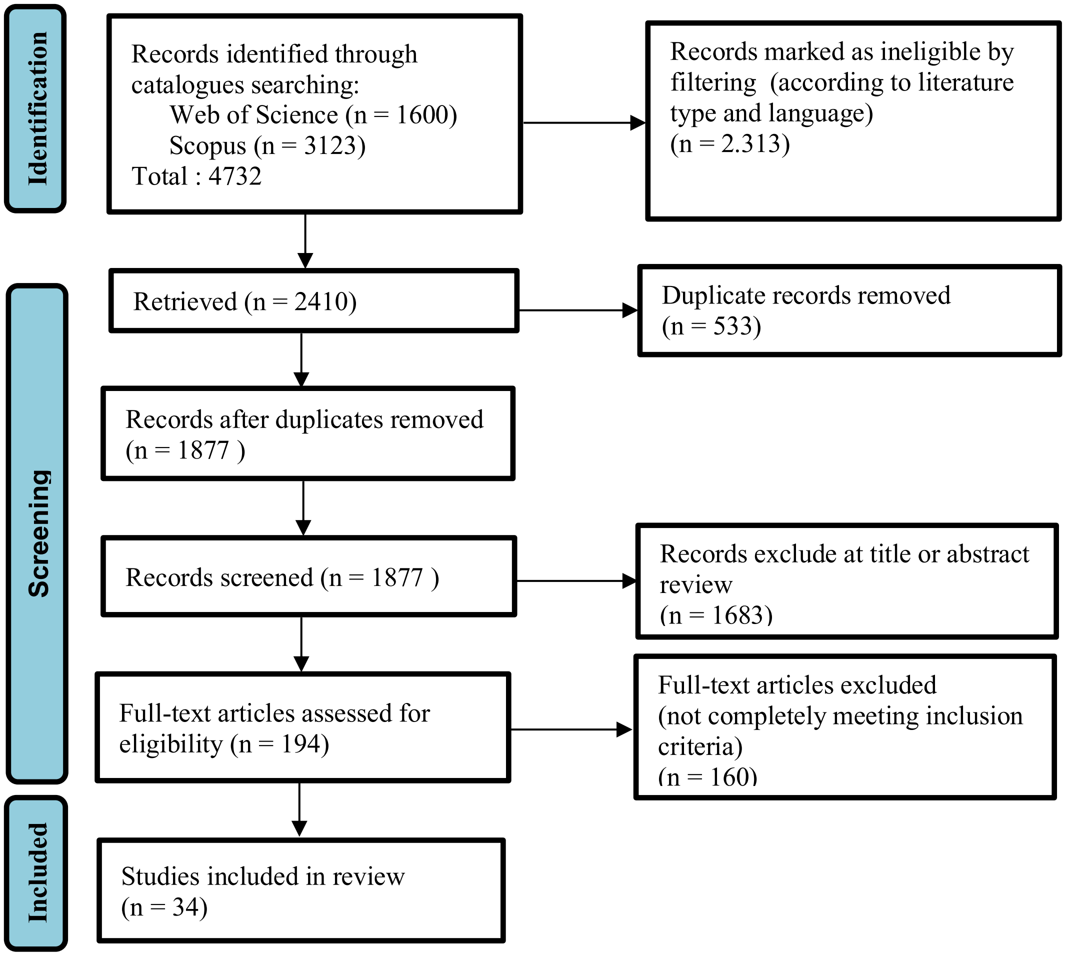

Figure. 1. PRISMA flowchart of the study selection processes of the systematic review

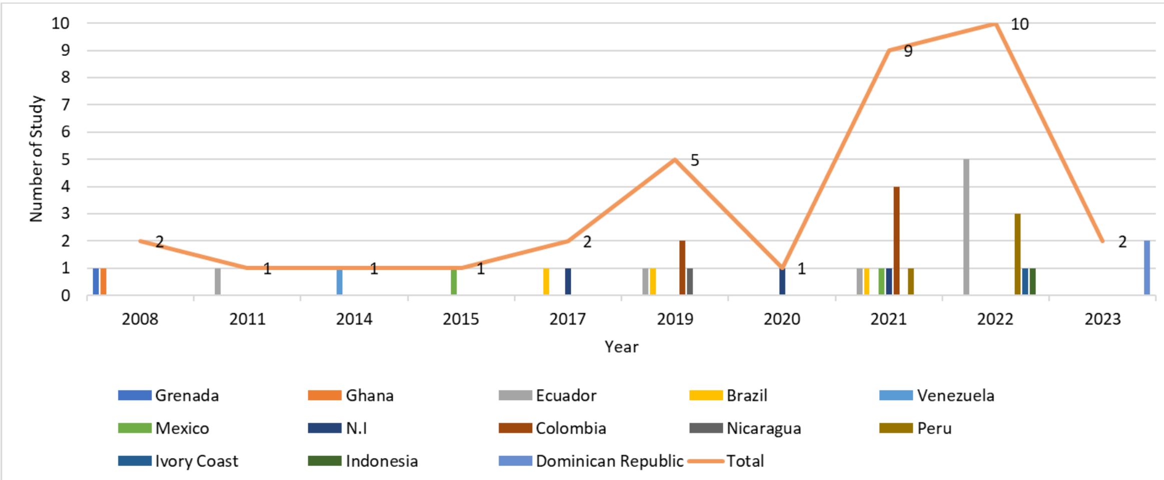

Figure. 2. The number of sensory descriptors research on FFC

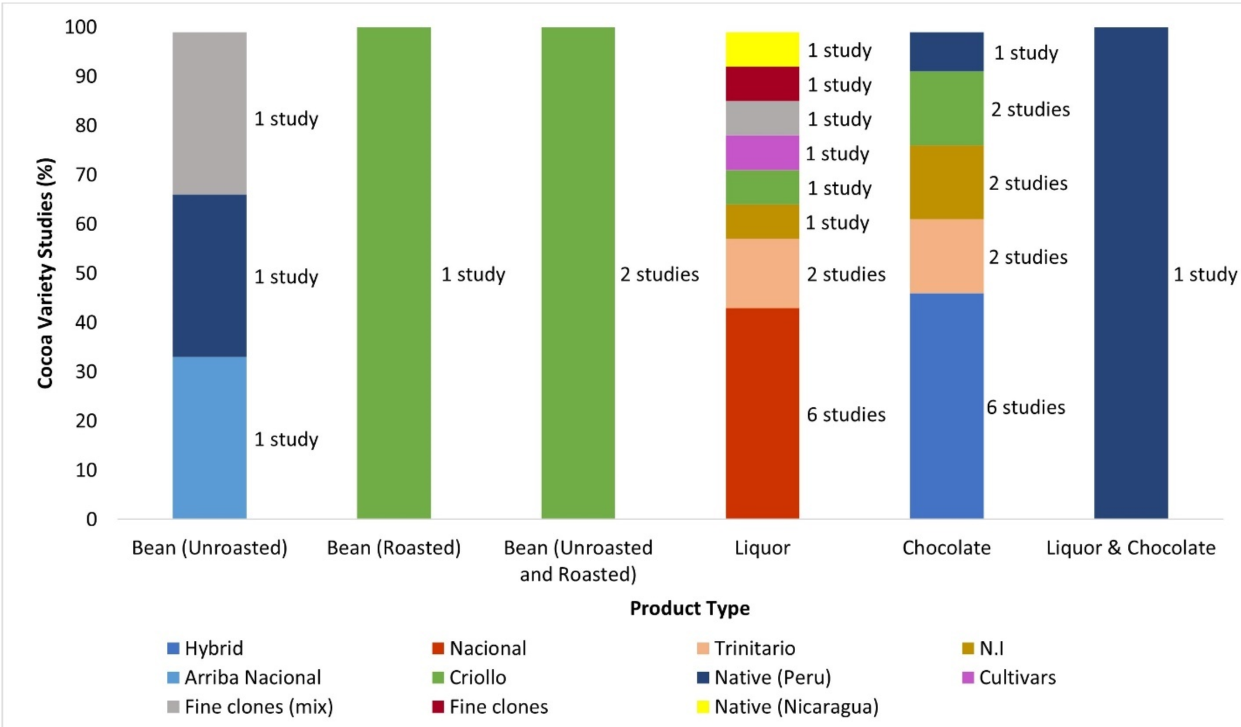

Figure. 3. Distribution of cacao varieties studied across sample forms

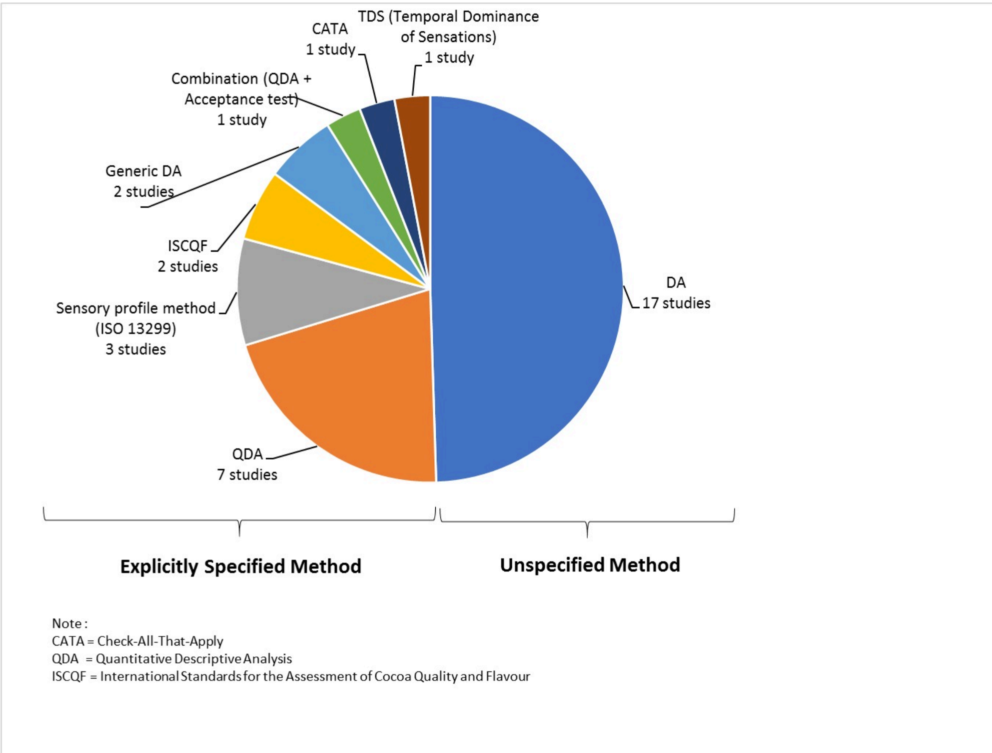

Figure. 4. Sensory methods applied in collected studies

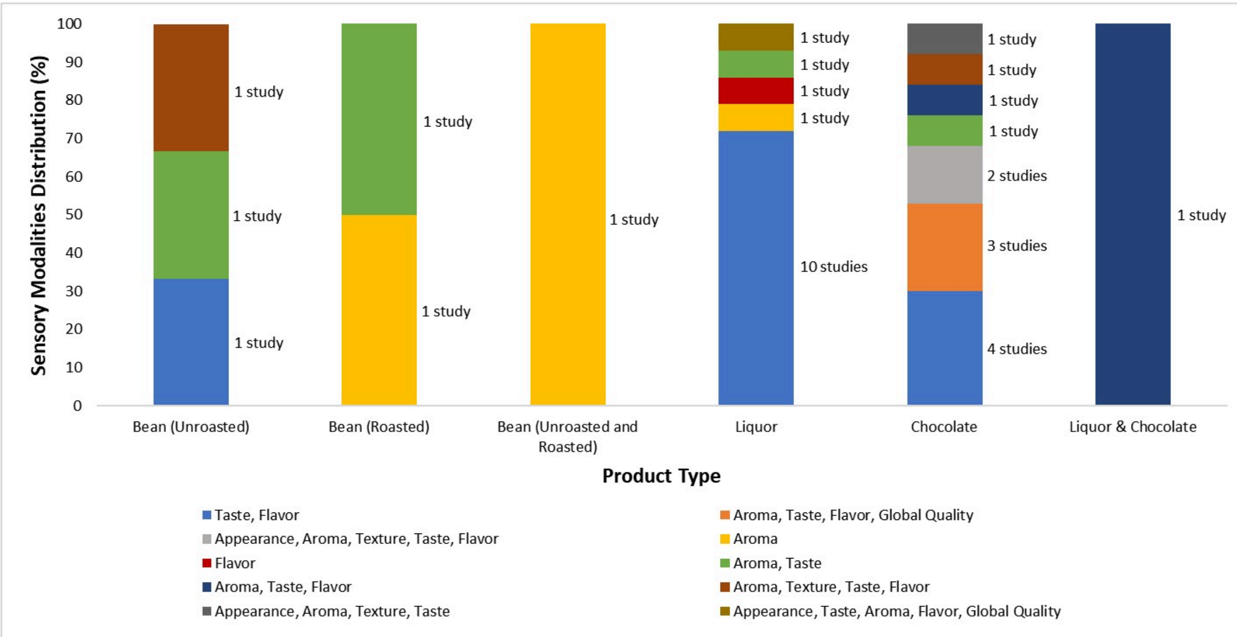

Figure. 5. Sensory modalities distribution across product types

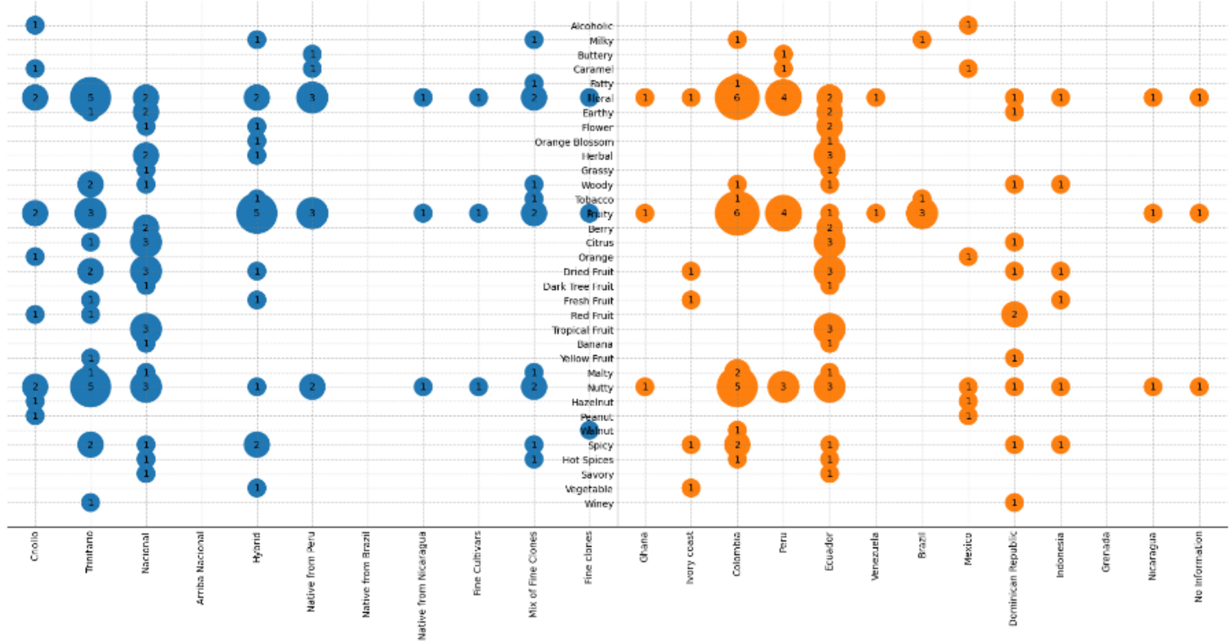

Figure. 6. Flavor outcomes by cocoa origin (right)