Review

Received: 4 July 2020 Revised: 3 January 2021 Accepted article published: 9 January 2021 Published online in Wiley Online Library:

(wileyonlinelibrary.com) DOI 10.1002/jsfa.11077

Quality differentiation of cocoa beans: implications for geographical indications

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Abstract

Geographical indications may stimulate collective actions of governance for quality control, trade and marketing as well as innovation based on the use of local resources and regional biodiversity. Cocoa production, however, dominated by small family agriculture in tropical regions, has rarely made use of such strategies. This review is aimed at understanding major research interests and emerging technologies helpful for the origin differentiation of cocoa quality. Results from literature search and cited references of publications on cocoa research were imported into VOSviewer for data analysis, which aided in visualizing major research hotpots. Co-occurrence analysis yielded major research clusters which guided the discussion of this review. Observed was a consensus recognizing cocoa quality resulting from the interaction of genotype, fermentation variables and geographical origin. A classic view of cocoa genetics based on the dichotomy of 'fine versus bulk' has been reexamined by a broader perspective of human selection and cocoa genotype evolution. This new approach to cocoa genetic diversity, together with the understanding of complex microbiome interactions through fermentation, as well as quality reproducibility challenged by geographical conditions, have demonstrated the importance of *terroir* in the production of special attributes. Cocoa growing communities around the tropics have been clearly enabled by new omics and chemometrics to systematize producing conditions and practices in the designation of specifications for the differentiation of origin quality.

Keywords: cocoa research; cocoa quality; geographical indications; territorial strategies; fermentation

INTRODUCTION

Geographical indications (GIs) of food and agricultural products claim a linkage between special quality attributes to *terroir* through a unique combination of conditions at a delimited territorial origin.[1] The recognition of such distinctiveness and reputation is protected by GI labels, which are regulated and implemented by a diversity of mechanisms under different legal frameworks and indication schemes.[2,3] Notably, GIs may play a dynamic role for the protection of cultural heritage, artisanal production and product identity as an evolving ecological system while promoting social learning in food quality governance and adaptation.[4,5]

In general, GIs have been recognized as effective differentiation tools, with discrimination favoring expensive products, and relevance conditioned by country-specific factors (such as culture and reputation).[6] However, registered geographical labels for cocoa beans are uncommon, which in part has been caused by the association between quality of chocolate and geography predominantly linked to locations of manufacturing and final transformations, rather than to cocoa beans as ingredients.[7,8] Nevertheless, a few studies have shown a strong influence on consumer perception of quality for chocolates made from origin-labeled cocoa,[7,9] while abundant chemometric research continues to elucidate the contributions of geography to cocoa quality diversity.[10–12]

Although several studies on cocoa quality provide the scientific background associating *sui generis* conditions with quality responses, recent works also challenge the weight of geographical variables. For instance, much research has focused attention on developing one-pot fermentation solutions for achieving consistent sensory profiles over traditional spontaneous processing.[13,14] Such research progress on postharvest technology has also enabled innovative perspectives less restricted by presumed relationships between cocoa varieties and quality.[15]

As agricultural and postharvest variables have been a matter of research regarding the effects on cocoa and chocolate quality,[16] farming systems around the tropics experience an increased demand for higher quality and productivity, together with an essential need to implement governance structures for guaranteeing sustainability.[17] In this context, GI strategies might represent an effective response to such complex challenges; however, efforts on their development require the understanding of research advances that may offer opportunities towards the determination of essential and relevant attributes bound to geographical origin.

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Thus, this review aims to analyze major research trends and discuss their implications for quality differentiation strategies. The article provides important insights into how current research progress enables the development of technical studies, which ultimately is a key step in the formulation of GI specifications. The study was based primarily on very recent literature, published during the last 2 years, whereas the methodological approach integrated previous publications (highly cited articles) to validate strategic research agendas.

EMERGING RESEARCH WITH FOCUS ON INTRINSIC QUALITIES OF COCOA BEANS

We reviewed recent publications on cocoa beans to identify hotspots based on bibliographical data, retrieved from Web of Science, searching 'cacao' or 'cocoa' in tittles (journal articles and reviews). Full records and cited references of publications from 2018 to 2020 were imported into VOSviewer 1.6.15 (Leiden University, Leiden, Netherlands) for data analysis (co-occurrence) and visualization. This approach was used to construct keyword maps and to visualize the existing connections among publications, hence facilitating the analysis of abundant literature in a diversity of disciplines.

Publications were grouped into five clusters of research, represented by different colors in Fig. 1, with descending order corresponding to the volume of publications. Cluster 1, represented by red, is observed as a highly dense zone with keywords from studies on chemometrics, fingerprinting and chemical profiles. Cluster 2, in green, included topics such as agriculture, agroforestry and climate change. Cluster 3 (blue) was associated with cocoa consumption and health effects. Cluster 4 (yellow) was associated with *Theobroma cacao* genetics, genome evolution and breeding strategies. Lastly, cluster 5 (purple) was linked to fermentation, microbiota studies, metagenomics and metabolomics.

The analysis demonstrated a major emphasis, with greater volume of publications (cluster 1), on the study of the intrinsic attributes of cocoa quality, which included amounts of organic acids, simple sugars, proteins, peptides, free amino acids, lipids, phenolic compounds and methylxanthines, or volatiles linked to aroma and flavor. Furthermore, a closer look into those publications revealed that current attention aims at analyzing origin effects and processing technology tackling the reproducibility of quality.[16,18]

Other research clusters, although relatively less numerical, are shown as current themes of attention driven by urgent social pressures, such as climate change, biodiversity management and sustainability (cluster 2); or consumption and effects on major

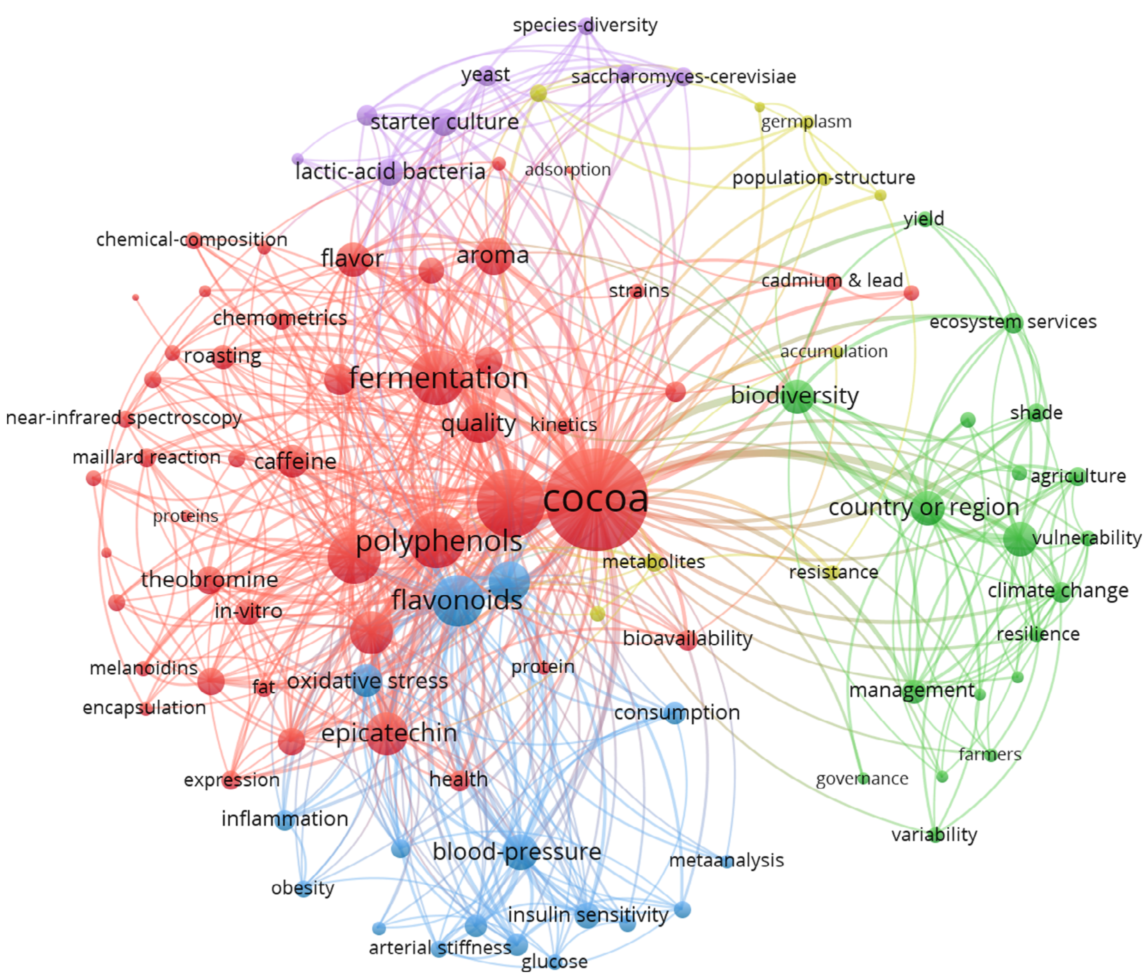

Figure 1. Analysis of hotspot occurrence based on bibliographical data for cocoa research from 2018 to 2020. Data analysis by fractional counting for co-occurrence of all keywords (minimum number of occurrences set at five). Visualization by fractionalization with minimum clustering size of 5 and resolution of 1. Network visualization with five clusters represented by different colors.

issues of human health such as emotions and cardiovascular conditions (cluster 3). Clusters 4 and 5 highlighted relevant areas of research during the last 2 years, sustained by the advances of the new omics for the understanding and improvement of the biological aspects of cocoa production (*Theobroma cacao* and fermentative microbiome).

To further contextualize our discussion on cocoa research trends and the implications for territorial differentiations, bibliographical data were also subjected to analysis for top author cluster identification (Fig. 2). This analysis included co-citation referring to most cited authors with a minimum of 20 citations in the last 2 years. Major themes were labeled to illustrate the location of these highly cited authors in their respective research domain. Results pointed out authors that have had a great impact on current research and continue to generate relevant discussions.

This bibliographical analysis guided a comprehensive overview in diverse fields, which revealed major research axes. First, a major focus was observed regarding techniques to study and enhancing aroma, and the use of chemometrics and fingerprinting for the traceability and optimization of quality, with most studies predominantly based on bulk cocoa.[19–22] Second, attention was observed in themes such as productivity and sustainability for the enhancement of the livelihood of farmers while promoting climate resilience.[23–25] Third, the consumption of cocoa and its impact on human health was observed as a major research driver, with studies on the identification and validation of bioactivity, with conclusive benefits for cardiovascular health, insulin signaling and intestinal and mental health.[26–30] Fourth were genetic studies on genotyping and variance for subsequent breeding strategies, with a major emphasis on disease resistance.[31–36]

The development of new omics boosted a momentum for fermentation research with new emerging approaches, varying from strain interaction (through metagenomics), technical and cultural practices for microbial ecology towards specific volatile responses (again, with special attention on the use of bulk cocoa), to the traceability of functional compounds originated during fermentation.[37–39] Regarding postharvest practices, publications showed an agreement that good processing standards have a greater significance than cocoa varietal factors. However, even for the same microbial species or within delimited producing regions, significant quality differences were observed, which pointed out the importance of both postharvest standards and geographical origin.[40]

COCOA GENOTYPES AND QUALITY PARADIGMS

Cocoa cultivars have been traditionally associated with generalized quality profiles, denoted by the dichotomy: bulk *versus* fine cocoa. From this perspective, cocoa has been for decades roughly grouped into three types with a range of hybrids in between. Two major ancestral groups have been classically recognized, with Criollos described as highly aromatic and fine cocoa (floral and smoother flavor), while Forasteros identified as rather vigorous with better yields and tolerance to diseases, but with less attractive sensory qualities (strong basic notes).[41] Trinitario cocoa, then,

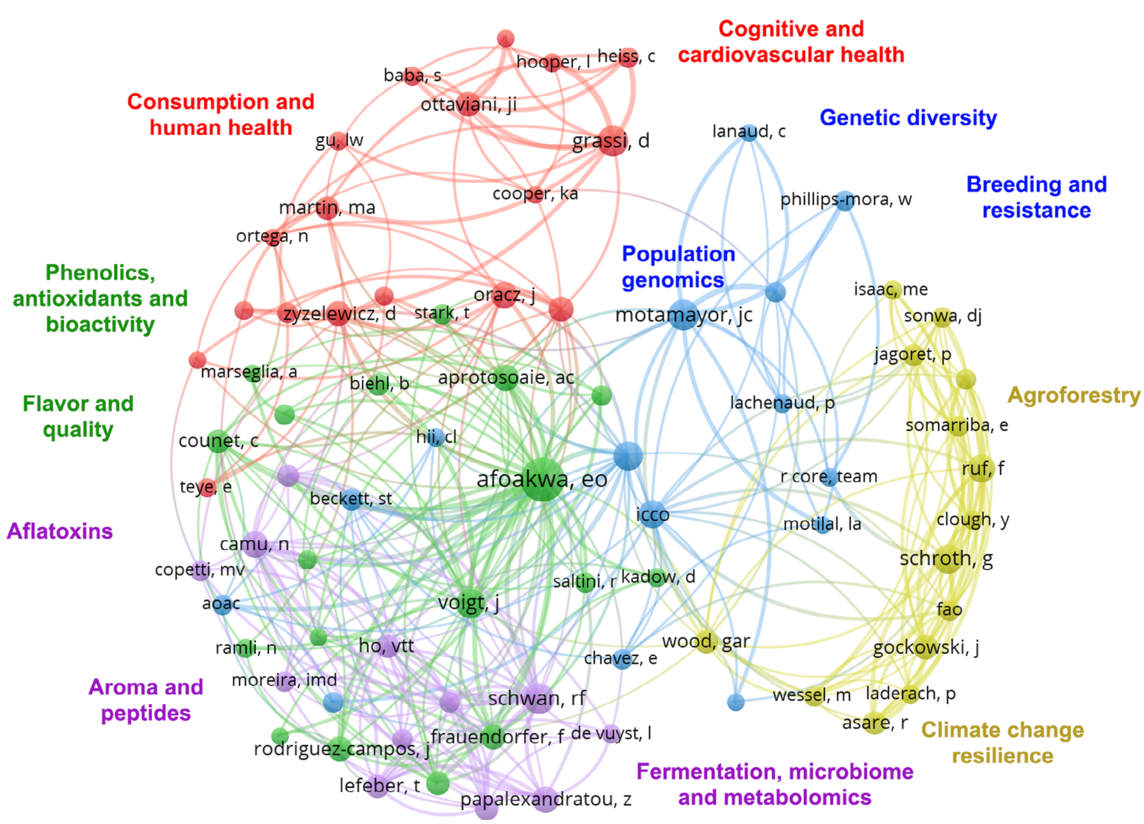

Figure 2. Analysis of top authors on cocoa research from 2018 to 2020. Analysis based on co-citation of authors by fractional counting, with a minimum of 20 citations per author from 2018 to 2020. Visualization by fractionalization (attraction 10; repulsion 0), with clustering minimum size of 10.

has been defined as a complex hybrid with characteristics originating from the two major ancestral lines.[42]

The classical view on cocoa diversity, however, has been redefined by a key study which, through genotyping with molecular markers and geographical clustering, characterized 10 genetically differentiated groups, namely: Criollo, Amelonado, Contamana, Curaray, Guianna, Iquitos, Marañon, Nacional, Nanay and Purús.[43] Further works have focused attention on cocoa genomic evolution and population dynamics pointing out a predominant selection for anthocyanins, theobromine and disease resistance, resulting in a majority of resilient populations.[44,45] In contrast, studies on the Criollo domestication process have shown the cost of improvement and selection of desirable traits leading to the accumulation of deleterious mutations.[46]

Notably, the cocoa genomic evolution reflects centuries of human and environmental selection associated with delimited geographical regions, adding to the importance of ancestry and cultural activity in its complex interaction with ecological factors for the construction of quality diversity. A recent review described the chronology of the societal issues and human decision processes influencing the genetic evolution of cocoa plantation from pre-Columbian to modern times.[47]

Modern cocoa breeding programs currently assisted by new molecular technology, undoubtedly, continue to accelerate the progress for achieving improved quality and productivity.[48,49] Nevertheless, remaining poorly understood is the impact of improved varieties on the *in situ* preservation of territorial diversity and quality, considering that breeding programs are constrained by conventional agricultural policies, technical criteria (increased yield, resistance and manageability) and strategies (tree selection through vegetative propagation and production of sexual families by open and controlled pollination).[50] Moreover, the impacts of traditional propagation of cacao by seeds from open pollination remain to be studied further, as these common practices may result in complex genetic structures and segregation of quality attributes.[51]

Extensive research has emphasized the importance of genotype contribution to quality, with a common example being the discrimination of bulk cocoa, such as CCN 51 (bitter, astringent and off-flavor attributes), from fine types, such as Nacional (fruity and acid).[35,52] Whereas other works, centered on the recognition of a complex genetic diversity in a territory, have pointed out major contributions from geography on the generation of distinctive aroma and flavor profiles.[53]

A review on the complex contribution of cocoa genotypes to quality variations, underpinned by geography, has highlighted the effects on contents of bean storage proteins, polysaccharides and polyphenols.[54] Other studies have also found variable concentration of compounds such as pyrazines (earthy), as well as linalool (citrus) among other terpenes, 2- and 3-methylbutanal (malty), methylpropanal (green, pungent) and phenylacetaldehyde associated with honey, green, floral. Organic acids such as citric acid are traceable compounds with impact on sensory descriptors recognized as differentiating volatiles for fine cocoa and origin,[55] while the origin traceability and fingerprinting of polyphenols[56] and minerals[57] have also been well studied. Additionally, the content of theobromine, caffeine and flavan-3-ols was found to differentiate samples of Nacional cocoa from different region in the same country.[58]

Moreover, challenging the conventional dichotomy of quality, bulk (Forastero type) *versus* fine cocoa (Criollo type), a major cluster of authors has emphasized the importance of postharvest parameters (pod storage, fermentation and roasting) over just cocoa genetics. These authors demonstrated the possibility of creating diverse flavor profiles, resembling fine cocoa, using bulk cocoa varieties, relying on optimized combination of postharvest conditions.[20,59,60]

FERMENTATION, MICROBIOTA DYNAMICS AND LOCAL CONDITIONS OF QUALITY

Cocoa bean fermentation is an essential postharvest stage taking 3–7 days, initiated by yeasts and lactic acid bacteria metabolizing carbohydrates and pectin from the pulp, succeeded by acetic acid bacteria, and gradually ending through the drying phase.[14,61,62] This process is directed at stimulating the formation of aroma precursors while minimizing bitterness and astringency.[54,55,63] Varying degrees and heterogenicity are determined by traditional methods applied in different countries,[64] including the use of banana leaves to cover the fermenting mass or specific types of fermenters such as heaps, baskets, wooden boxes, trays and platforms.[15]

The prevailing consensus regarding cocoa distinctive aromas and flavors (before roasting, conching and other processing stages) is that they primarily originate from the interaction of cocoa genotypes and fermentation. For instance, studies on metabolic dynamics have distinguished the formation of some volatiles as pulp-derived (linalool, β-myrcene, 2-heptyl acetate) or intrinsic to the bean (2-heptanol, 2-heptanone, 2-pentanol), while others are generated during fermentation by microbial synthesis (higher alcohols, aldehydes, ketones, organic acids, sugar alcohols (lactic acid bacteria and yeasts) and esters (yeasts)).[14,40,63] Additionally, the effects of cocoa genotypes and fermentation systems on microbial activity have been linked to the diffusion of internal epicatechin and theobromine from the bean cotyledons into the pulp[65]; however, more research is needed to analyze the influence of such diffusions on microbiota diversity and successions.

The interaction of cocoa origin and fermentation has been also explained through a diversity of Amadori compounds, which have been suggested as important quality markers.[66] Moreover, amino acids and peptides have been highlighted as genetic-origin derived, but also mostly related with particular fermentation methods applied in specific geographical origins.[67] Particularly, oligopeptides derived from the vicilin-class (7S) globulin of cocoa beans have been recognized as essential for the formation of the cocoa-specific flavor.[68]

Major progress towards the understanding of quality modulation has been facilitated by studies focused on microbiological diversity in cocoa fermentations from different origins. It has been confirmed that postharvest practices of cocoa overrule the impact of varieties, although significant microbial differences can be observed for different regions within the same country.[40] Microorganism succession, interactions and dominating strains, themselves determined by fermentation techniques and inoculum (either controlled or naturally present), impart strong effects on the volatile and metabolite composition of final products. Hence, the selection of microbial consortia for controlled fermentations with starter cultures has demonstrated the role of yeast and bacteria for the replication of quality.[14,15,64,69–71] For instance, key aroma markers, in particular higher alcohols, phenylethyl alcohol and corresponding esters, have been associated with *S. cerevisiae*, *H. opuntiae*, *P. kudriavzevii*, *L. plantarum*, *A. pasteurianus*, *K. marxianus*, *C. inconspicua* and *L. fermentum*.

While off-notes have been related to over-fermentation and the presence of *Bacillus* spp.[40,72]

Cocoa microbial communities and resulting cocoa volatiles are highly conditioned by fermentation technique, with pod storage,[20] turning frequency[73] and fermenter type playing key roles in the formation of predominant volatiles. For example, it has been demonstrated that cocoa beans fermented in boxes show increased concentrations of alcohols and esters compared to heap fermentations, given a faster carbohydrate metabolism and greater production of organic acids. Authors have also suggested necessary minimal or no storage of pods prior to fermentation for preserving fruity, floral and spicy flavor notes, as well as prolonged storage for enhancing volatiles exhibiting more cocoa, chocolate, nutty and roasted flavor notes.[74,75] Little has been published, however, on the specific effects of diverse woods used in the construction of fermenters, whereas biochemical exchanges between the wood and the fermentation mass has been well studied in other food bioprocesses.[76]

While spontaneous fermentations have been the traditional norm in most countries, the controlled fermentation relying on the inoculation of selected microorganisms remains a major field of research.[15] Nevertheless, discrepancies are expected when using such starter cultures as cocoa fermentation practices change depending on the geographic origin. Therefore, it is the consensus that cultural factors influencing fermentation techniques, agricultural practices, microenvironmental factors as well as cocoa genotype, and the composition of the microbiological inoculum, determine the complex metabolite dynamics during fermentation, which finally results in specific differentiated aroma and flavor profiles.[40,64,71] Thus, this diversity of conditions and cultural factors influencing fermentation have shown a clear clustering by farm, highlighting the importance of farm protocols for generating unique fingerprinting based on microbiome dynamics.[64] From this perspective a key cluster of research ('de Vyust-Papalexandratou *et al.*') has consistently demonstrated the essentiality of good fermentation practices, working on the direction of optimized starter cultures, yet recognizing the influence of local factors and techniques on differentiated and optimized sensory profiles.[14,40,61]

As the chocolate industry is increasing the demand for high outputs of differentiated products exhibiting unique flavors, researchers have dedicated efforts to the development of technology for varietizing bulk cocoa, by enhancing the aroma and inducing distinguishing attributes in otherwise generic products.[14,20] Some recent works have even considered the design of remote fermentation practices, away from on-farm sites, pursuing geography-independent technologies.[21] Thus, evidently, the development of controlled fermentation technology may represent a challenge to origin cocoa, as the optimization of starter cultures and fermentation systems aims at varietizing bulk cocoa beans regardless of the location. However, the use of starter cultures not only has been approached for the modulation of microbial communities, or the production of improved sensory profiles, but also optimizing fermentation time while minimizing quality defects.[77]

The development of robust methodologies for metabolomic and microbiome studies can facilitate the recognition of local contributing factors for community- or regional-based strategies, towards the origin differentiation of fine cocoa. As an example, high-throughput sequencing of molecular markers for bacteria and yeasts has been used for clustering by farm or region, identifying the effects of farm protocols, climate and bean mass exposure on the dynamics and composition of microbial communities.[64] Additionally, the isolation and use of dominant microbial species from spontaneous fine cocoa fermentation have been recommended as inoculum for differentiated qualities, adapted for specific farm/region and good processing practices.[78]

Thus, territorial strategies could consider the selection of starter cultures based on local biodiversity for a systematic optimization of differentiated qualities, as well as in consideration of local processing practices, genotypes and market demands. Also, studies for the recognition of local microbiota could be essential in the design of protection strategies and the development of designation specifications for origin cocoa.

NUTRACEUTICAL PROPERTIES AND HUMAN HEALTH

A recent systematic review has concluded that cocoa consumption plays an important role in the human metabolic pathway through reducing oxidative stress, which is widely known to play a key role in in pathogenesis of chronic diseases such as diabetes, cancer and cardiovascular disease.[79] Other recent studies have observed the effects of cocoa on the intestinal microbiota composition, which in turn have been linked to an improved glucose homeostasis and gut health.[80–82] Most publications linked those cocoa benefits to phenolic acids, and particularly flavanol composition, compounds that have been found to be dependent on cocoa origin.[83] But also, some works have associated bioactive properties with oligopeptides from artisanal fermented cocoa.[84]

A major cluster of authors has extensively investigated the effects of cocoa bioactive compounds on human health.[85–87] Further studies had confirmed the role of bound phenolic acids and high-molecular-weight melanoidin.[88–90] This research group has also suggested the differential antioxidant properties and composition of Criollo over Forastero and Trinitario. The authors have pointed out the influence of additional factors such as climate, agricultural systems, postharvest practices and storage conditions on the resulting bioactive properties.

In addition, recent reviews have studied the effects of cocoa consumption on human mood and cognition. Once again, the authors suggested the importance of geographical origin and processing conditions, which had significant impacts on phytochemical composition and consequently on bioactivity. These works described the complex relationship between cocoa consumption and psychopharmacological actions; however, a possible synergistic interaction has been highlighted with contributions from specific bioactive compounds such as flavanols and salsolinol, as well as from orosensory properties.[91,92]

Clearly, the interaction of genotype, fermentation and origin remains fundamental in the determination of bioactive properties of cocoa. Optimized fermentation, for example, has been used for enhancing the antioxidant capacity of cocoa, as some yeasts are actively involved in releasing bound phenolic compounds resulting in higher free phenolic contents.[93] These authors have specifically shown the enhancing capacity attributed to yeast cultures based on *H. thailandica* and *P. kudriavzevii*. Moreover, a review on functional volatiles from inoculated fermentations has shown potential health effects, with important evidence revealing anticarcinogenic and antinociceptive activity of limonene, antitumor activity of benzaldehyde and antioxidant activity of benzaldehyde and its derivatives. The authors highlighted the capacity of volatiles to stimulate human mood and emotions.[71]

Finally, cocoa consumption has also been studied regarding safety risks with most recent works concerning cadmium concentrations. These investigations observed the influence of postharvest practices, soil geography as well as genotype on the presence of heavy metals in cocoa beans.[56,94–96] Most importantly, research has aimed at developing cultural and processing practices for mitigating and reducing cadmium concentrations, thus laying out strategies for minimizing health risks.[94]

AUTHENTICATION AND GEOGRAPHICAL DIFFERENTIATION OF QUALITY

As cocoa genotype evolution, together with hybridization practices and breeding programs, results in special population dynamics,[43,46] molecular methods have been developed in the recognition of the resulting genetic diversity in cocoa producing-regions. In particular, molecular marker-based protocols and the use of single nucleotide polymorphism have been well developed for cocoa genotyping.[36,53,97–99] This methodology has been effective in the determination of provenance and geographical delimitation.

However, quality control techniques continue to aim towards more efficient and appropriate methodologies for the traceability of cocoa signatures. Chemometric methods have been implemented for characterizing key compositional markers such as volatiles,[12,100–103] fatty acids,[104] peptides,[11,67,105] bioactive compounds[82,106,107] and methylxanthines,[58,60] as well as heavy metals[56,108–111] and other contaminants.[112,113] From this perspective, a recent review on the traceability of cocoa origin has summarized and discussed destructive and nondestructive technologies providing examples aiming at assessing cocoa quality, the study of new functional properties, the detection of trace contaminants and the detection of authenticity.[10]

Noteworthy, near-infrared spectroscopy has been extensively applied for the rapid nondestructive authentication and geographical classification of cocoa beans.[114–117] Recently, a combined near-infrared hyperspectral imaging and chemometric method has been developed for the discrimination of cocoa hybrids.[118] However, gas chromatography and mass spectrometry (particularly headspace solid-phase microextraction/gas chromatography–mass spectrometry) continue to be used for identifying cocoa based on aroma fingerprints in the interaction with geography.[12,19]

Regardless of the instrumental approach, multivariate analysis has been essential for obtaining relevant and reliable results. Principal component analysis, one of the most common statistical approaches for the analysis of compositional data, has been particularly useful by enabling better visualization of variance and discrimination patterns.[12,19,66,119,120] Other approaches have included hierarchical cluster analysis,[20] and principal component analysis with partial least squares discriminant analysis or partial least squares regression for further discrimination.

TERRITORIAL STRATEGIES FOR DIFFERENTIATION OF COCOA QUALITY

The literature has extensively demonstrated the influence of geographical, cultural and ecological factors on cocoa quality (Fig. 3). However, an effective GI strategy must correspond with the interests of concerned institutional actors and territorial stakeholders, as well as responding to market relevance.[3,4,9] Additionally, the use of appropriate strategies depends on each country's legal framework for the recognition and protection of GIs. A review has discussed the concept of *terroir* of agricultural products emphasizing the importance of metabolites as a response to cultural and environmental factors, as well as justifying the significance of agronomic and postharvest practices, all of which have been extensively studied in regards to cocoa quality.[1]

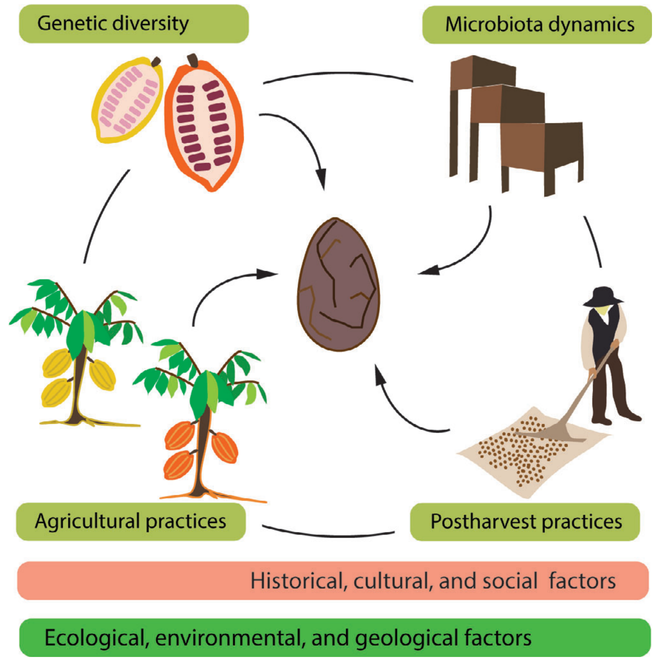

Figure 3. Diagram representing the multidimensional nature of cocoa quality influenced by cocoa genotypes, microbiota dynamics and postharvest and agricultural practices. These interactions are underpinned by ecological, environmental, historical, cultural and social dimensions associated with the territory.

Protected designations of origin and protected GIs, for instance, have been considered effective and dynamic, being adaptable to relevant social demands or market forces. Thus, evolving socioeconomic conditions and changes in the biophysical environment can also trigger amendments to product specifications in the consideration of new demands.[5] Correspondingly, recent research on cocoa has responded to current issues of relevance from social and market standpoints, which in turn provides a base for the development of community-based strategies towards the innovation and differentiation of quality.

As seen throughout this review, several quality-determining factors are closely bound by complex interactions and are highly relevant in the definition of these strategies. Therefore, community-based strategies must promote the participation of key territorial actors for the designation of specifications from a multidisciplinary perspective. Hence, it is necessary to develop the description of genotypes, harvesting and postharvesting protocols, fermentation technology for the modulation of desirable flavor and aroma profiles, compositional analysis of key compounds as origin markers, as well as agricultural conditions and practices. Moreover, it is fundamental to incorporate the consideration of historical, environmental and cultural aspects for sustainability in response to institutional, social and market demands.

CONCLUSIONS

This review has presented recent progress on technical advancements regarding quality differentiation of cocoa beans. Network analysis provided an in-depth comprehension of major research clusters focused on the study of intrinsic cues. The consensus is that quality can be extensively differentiated by the interaction of cocoa genetics and fermentation microbiome, underpinned by geographical factors (territorial, environmental, cultural and social factors).

Thus, human pressure throughout the historical production of cocoa has generated origin quality mirrored in the selection of genotypes and fermentation practices (systems and preferred microbiome successions), which associated with ecological, cultural and market-oriented aspects have yielded a diversity of distinguishable cocoa bean profiles.

The increased demand for varietal and origin cocoa has created challenges and opportunities for farming communities around the tropics, to encourage the systematic control of production and processing practices. Moreover, the advances in omics and chemometrics for the analysis of key markers of quality can facilitate efforts towards the development of preliminary studies, and the designation of specifications.

Efforts towards the promotion of GIs must rely on the coordination of actions with success and evolution being closely related to effective governance. Furthermore, GIs may promote community-based dynamics for prestige construction and protection while fostering innovation. Overall, the implementation of GI strategies can stimulate a collective approach to quality control and trade, as well as may encourage processes for territorial innovation based on the use of local biodiversity, cultural and institutional resources.

Cocoa quality diversity could be boosted by further research aimed at better understanding the traditional production of cocoa, with special attention on key microorganism dynamics influenced by specific cocoa-genotype factors (pulp characteristics and biochemical diffusion into the pulp), and vice versa the effect of recognized microbial ecosystems on specific cocoa genotypes. Also, more studies are needed on the contribution of local bioresources such as the types of wood used in fermenters, aeration practices and the ecology of dominant and volatile active microorganisms.

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