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Herramientas de innovación tecnológica para cafés especiales a partir de instrumentación para análisis de calidad: Una revisión sistemática

Technological innovation tools for specialty coffee from quality analysis instrumentation: A systematic review

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Resumen: *En la cadena de valor del café, el proceso ideal debería ser como un proceso continuo y predecible. Esto no es posible para la industria del café porque cada proceso de cosecha, procesamiento y almacenamiento es diferente e influye en el producto final. Además, la automatización del proceso de tostado es limitada porque las percepciones sensoriales como el olor, sabor y color del café aún no son totalmente ajustables desde diferentes fuentes instrumentales. Se necesita más investigación sobre este tema. Este artículo presenta los resultados del estudio de mapeo sistemático destinado a evaluar las herramientas de los sistemas instrumentados para el análisis de la calidad del café de especialidad y de origen. Se consolidaron 172 documentos para estudiar los avances en innovación y cambio tecnológico para el sector del café, y los resultados indican que a través de la técnica de fusión de datos de los sistemas E-Nose y E-Tongue, y E-Eye, se identificaron y clasificaron cafés según su color de tostado, aroma y sabor, y se cuantificaron sus atributos organolépticos, ofreciendo una herramienta de competitividad como complemento a un proceso tradicional de evaluación de calidad realizado por un panel de catadores expertos, el cual puede ser apoyado por el análisis de datos multivariados, el tratamiento y procesamiento de datos y visual, olfativo y señales de sabor, para representar un diagnóstico de la calidad del café tostado como una herramienta de innovación para las comunidades cafetaleras. Se propone un esquema de integración de las tecnologías instrumentadas para la evaluación de la calidad del café como un elemento de transferencia de tecnología de la industria 4.0 en la agro-cadena del café y su papel en la competitividad y desarrollo rural del café.*

Palabras Clave: *Calidad del café; industria 4.0; E-nose; E-tongue; E-eye; Tostado de café; Entrenamiento SCA; Sabores y aromas del café.*

Abstract: *In the coffee value addition chain, the ideal process should be like a continuous and predictable process. This is not possible for the coffee agribusiness because each harvesting, processing and storage process is different and influences the final product. In addition, the automation of the roasting process is limited because sensory perceptions such as smell, taste and coffee color are not yet fully adjustable from different instrumental sources. Further research on this topic is needed. This article presents the results of the systematic mapping study aimed at evaluating the tools of the instrumented systems for the analysis of the quality of specialty and origin coffee. 172 documents were consolidated to study the advances in innovation and technological change for the coffee sector, and the results indicate that through the technique of fusion of data from the E-Nose and E-Tongue, and E-Eye systems, coffees were identified and classified by their roasting color, aroma and flavor, and its organoleptic attributes were quantified, offering a competitiveness tool as a complement to a traditional quality assessment process carried out by a panel of expert tasters, which can be supported by the analysis of multivariate data, the treatment and processing of data and visual, olfactory and signals and of flavor, to represent a diagnosis of the quality of roasted coffee as a tool of innovation for coffee communities. A scheme of integration of the technologies instrumented for the evaluation of the quality of coffee as an element of technology transfer of industry 4.0 in the coffee agro-chain and its role in competitiveness and rural coffee development was proposed.*

Keywords: *Coffee quality; industry 4.0; E-nose; E-tongue; E-eye; Roasting coffee; SCA training; Flavors and aromas of coffee.*

Introduction

The quality of coffee expressed in different factors especially depending on its geographical origin, environmental and genetic factors and others related to agricultural practices, its storage and the preparation of the drink (Cheng et al., 2016; Mestdagh et al., 2014; Puerta Q et al., 2016). Important differences have been found in the taste and aroma of coffee that are directly related to the physical, chemical, and physiological alterations that occur in the beans during the stages of their processing. Colombian coffee has a quality recognized worldwide and has been appreciated by roasters as one of the best within Arabica coffees and are the subject of constant study to generate quality control strategies in the coffee value chain (Bosselmann et al., 2009; Lee et al., 2015; Moroney et al., 2015; Puerta Quintero, 2016; Sunarharum et al., 2014) The most important roasters in the United States, Brazil, Germany and Switzerland, for example, have different preferences regarding the characteristics of coffee and have made great progress in roasting and sensory analysis of selected coffee batches. The best known methods for the quality control of coffee roasting have been the visual, olfactory and flavor comparison made by a panel of tasters duly trained under an evaluation protocol, demonstrating expertise and experience with the diagnosis of the quality of the sample of previously roasted and prepared coffee(Correa et al., 2011; Diezma & Cristina, 2011) This evaluation is contrasted with the quality evaluation format of both roasted coffee and beverage according to the Specialty Coffee Association (SCA), taking into account the lexicon of flavors and aromas defined by The World Coffee Research Organization (Chambers IV et al., 2016).(Chambers IV et al., 2016)

Traditionally, a panel of trained experts evaluate coffee quality parameters to identify, define and understand the sensory characteristics that determine that quality (N. Gutiérrez & Barrera, 2015) The method of quality assessment based on human sensory inspection relies heavily on the senses of vision, smell and taste, to define and identify the parameters of appearance, color, aroma, acidity, bitterness, body and taste of the drink, respectively, and tend to be subjective, despite the training provided, as this evaluation may contain perceptions or omissions of the operator by not being able to confirm any abnormality in the coffee, the use of inadequate statistical techniques, or the misinterpretation of the data. This fact has generated disadvantages related to the costs of their training, the time invested to analyze the samples, and the discrepancies that may occur between each taster (intra-observer perception) and between the cupping panel (inter-observer perception), due to tiredness, fatigue, stress, and some non-pre-existing diseases that experts may suffer and that generate subjectivity in the process of quality evaluation and expression. flavor of roasted coffee. This problem has been addressed since the calibration of the taster panels using the SCA protocols and their respective calibrations and recalibrations that must be performed annually (Brudzewski et al., 2012) Currently there is no complete technological approach that allows to contribute instrumentally in this aspect.

In order to advance the state of the art in the sensory evaluation of coffee, the member countries to the society of specialty coffees - SCA and the large roasting companies, have integrated into their quality evaluation process, robust laboratory analysis techniques such as, for example, liquid chromatography (Blumberg et al., 2010; Hečimović et al., 2011; Luca et al., 2016; Moreira et al., 2001; Y. Wang & Kays, 2003)gas chromatography (Bolivar et al., 2017)infrared spectroscopy (Barbin et al., 2014; Franca & Oliveira, 2011; Gordillo-Delgado et al., 2017; L. S. Oliveira & Franca, 2011; Páscoa et al., 2014; J. R. Santos et al., 2016; Tolessa et al., 2016) mass spectroscopy (Amorim et al., 2009; Charles et al., 2015; Gloess et al., 2014; López-Darias et al., 2011; McEwan, 2015; Piccino et al., 2014; J. S. da Rosa et al., 2016; Şemen et al., 2017)nuclear magnetic resonance (NMR) (Arana et al., 2015; Cagliani et al., 2013; Consonni et al., 2012; Kodani et al., 2017; Spyros, 2016; Wei et al., 2014)among other techniques for evaluating physical and chemical properties (Bressanello et al., 2017; Casas et al., 2017; P.R.A.B. De Toledo et al., 2016)which manage to evidence and identify some of the most important components of coffee in a wide range, and increase expectations in coffee quality standards for all actors in the coffee value chain, in terms of the quality, speed and objectivity of the evaluation (Ghasemi-Varnamkhasti et al., 2010; Sanaeifar et al., 2014) These latter concepts represent a constant challenge for the coffee scientific community and have been addressed with the development of industrial instrumentation systems (Berk, 2009; Kiani et al., 2016a; Mendez, 2016) In particular, the electronic nose (E-Nose) and the electronic tongue (E-Tongue) are on the market, which stand out for providing a solution to the standardization of instrumented methods that support the evaluation of the quality of roasted coffee (Omatu & Yano, 2016; L. Zhang & Tian, 2014)(J. M. Gutiérrez et al., 2013; Hauptmann et al., 2000; Oliveri et al., 2010; Sundic et al., 2000; Yasuura & Toko, 2015) With the use of these tools, it has been possible to identify as the majority indices of roasted coffee and its beverage indicators that account for bitterness (caffeine, chlorogenic acid and its decomposition into phenols), acid (acetic and citric acid) and the most representative volatile organic components (VOCs), typical of the roasting process (CO_2,H_2O, pirazines, esters, aldehydes),managing to correlate them with the indicators of the sensory evaluation protocols managed by the coffee society SCA specials (Colzi et al., 2017; Grosch, 2007; Monica Lee et al., 2001; Poisson et al., 2017; SCAA, 2015; Sunarharum et al., 2014; A T Toci & Farah, 2014; Aline T Toci & Farah, 2008)

On the other hand, to identify physical properties such as color, colorimetry and/or artificial vision techniques known industrially as E-Eye have been used (Apetrei et al., 2010; S Buratti et al., 2017; Oblitas Cruz & Castro Silupu, 2014; Gloria Puerta, 2009). An exploration of instrumented systems for food quality analysis currently reports the use of fusion of data from the E-Nose and E-Tongue systems, and E-Eye (Apetrei et al., 2010; Susanna Buratti et al., 2018; Kiani et al., 2016a; Lvova et al., 2015)in which it is intended that they not only identify and classify colors, smells and flavors, but that these attributes are quantified, offering a diagnostic tool as a complement to a quality evaluation process carried out by a panel of expert tasters, but supported by multivariate data analysis that can integrate the treatment and processing of data and visual signals, olfactory and flavor, to represent a diagnosis of coffee quality in terms of the SCA protocol and generate decisions regarding the differences found in the process (Susanna Buratti et al., 2018; Dutta et al., 2011; J. M. Gutiérrez et al., 2013; Haddi et al., 2014)

Objective of review

Today there is an increase in the production of specialty and origin coffees, highly desired for their organoleptic properties and exclusivity in aromas, flavors, and nuances and to understand the integration of biomimetic inspection systems for the analysis, evaluation and control of the quality of coffee in the roasting stage. In this case, this trend constitutes a potential contribution to progress in the field of industrial automation (Borràs et al., 2015; Susanna Buratti et al., 2018; A. R. Di Rosa et al., 2017; Dunkel et al., 2014; Lvova et al., 2015; Peponi et al., 2017; Pigani et al., 2018; Wasilewski, Gebicki, et al., 2017) applied to the coffee production chain as a product value addition strategy. Therefore, it is necessary to understand how the different technologies for the evaluation of coffee quality can be integrated and project the inclusion of industry 4.0 in the daily tasks of both the panel of tasters and rural producers. The objective of this review is to understand the previous research of coffee quality evaluation systems, in such a way that the main trends in qualitative and quantitative tools, the research gaps and the most important problems to be considered on the subject of new studies related to the democratization of Industry 4.0 technology, in the development and quality control of high-quality specialty coffee products are exposed. It reviews tries to visualize the potential of technology-based coffee quality assessment tools, to analyze processed, roasted or ground products, offered by coffee growers, cooperatives, and small producers of the grain that, from the rural sector, have very local projects, but that are they can enter the international market with the support of technologies that allow them to obtain data from sources such as sensors and specialized electronic instrumentation. It proposes for the first time the relationship between existing tools for the analysis of “roasted coffee at source" products, and their possibility of increasing competitiveness based on the adoption of new technologies of electronic instrumentation and multivariate data analysis.

Research questions

Four questions were asked concerning coffee samples, their origin, harvesting and post-harvest processes, beverage preparation methods and data analysis tools.

RQ1: What techniques have been used to identify and classify coffee according to its origin, variety, benefit, value addition and sensory profile?

RQ2: What is the relationship and importance between the degree of roasting of coffee and the sensory attributes of fragrance, aroma, acidity, bitterness, body, and overall flavor?

RQ3: What techniques have been used to identify the aroma and flavor components of roasted coffee?

RQ4: What are the non-trivial techniques for determining smell and taste of roasted coffee, applied to the quality assessment process?

Systematic review protocol

The methodology of systematic mapping of the literature has been taken as a reference (Petersen et al., 2015) in order to establish a starting point around the existing coffee evaluation tools in the field. This work establishes a procedure consisting of five stages:

1. Take the research questions.
2. Perform the literary search.
3. Select studies.
4. Classify items.
5. Extract and perform data aggregation

The systematic review followed the sequential steps so that they can be replicated in future research. First, searches on the topic were conducted in different databases and were carried out following the same procedures to establish the same search conditions. Thus, the same filters and exclusion inclusion criteria were used. Secondly, the classification by categories of searched documents was carried out to find an answer to the questions posed. A reading of these documents was made and those that did not meet the established inclusion criteria were discarded. The selected documents were collected in a single database and duplicates were removed. Finally, the selected documents were read and analyzed independently using concept maps, establishing conclusions and relationships between them. In this way, the review protocol allowed a more complete search with less risk of bias and that can be reproduced in various contexts. The search strategy was performed through an initial selection of keywords and the construction of the different search equations. To search for the documents, the following keywords were used: "roasting coffee quality", "electronic", "nose", "tongue", "eye". With these keywords, the search equations were constructed, using AND and OR connectors in the TITLE-ABS-KEY field. To implement the search strategy, keywords related to the topic were used, mainly in the English, Spanish and Portuguese languages. The search strings used were used in the Science Direct, IEEE, EBSCO and SCOPUS databases.

Inclusion criteria

In this review, the inclusion criteria relate of documents records by origin, language, topics, and year of publication. We considered peer-reviewed articles for scientific and technical peers. Therefore, the types of documents included were those marked as originals and review articles written in English, Spanish or Portuguese, and published between 2010 and 2020. There is a particular interest in researching the medical benefits of coffee drinking, and the flavor expression of specialty coffees, so this item was included as a criterion.

Exclusion criteria

As in the inclusion criteria, the types of documents, the population sample, the stimuli, and the experimental design were considered. Documents with opinions, views or anecdotes were discarded. The exclusion criterion allowed to discard some of the combinations of search strings in which the relevant information was obtained, but, in addition, an enormous amount of information that is not useful for the study and diverted the analysis and conclusions related to the main topic and the research question. In this way, with these keywords, logical operators and search equations in the title, abstract and keyword fields, the documents were searched using selected databases.

Results

After presenting the methods to carry out this review, the results obtained are shown. The studies selected in this review present the characteristics of biomimetic systems with significant variability in the use of one or more nose, eye, or electronic tongue technologies. Therefore, the indicators found, the most common elements and the differences between the reviewed investigations are presented. Sequentially, the characteristics of the technologies used in the selected studies and their contribution to the evaluation of coffee using color as a global and complex indicator are shown. Then, a section on the different links between electronic nose and tongue systems for food analysis, inspection and quality control is presented. After this, the data analysis and processing tools that are often used in the selected investigations are presented. Finally, the most common measured variables are presented in this review.

Systematic review of the literature

Table 8 shows the keywords used, combined with the connectors to form the search strings used to select the relevant works within the theme of this study.

Table 1. Classification of information found in selected databases.

Keywords/Connector Combinations/strings		DATABASE	# Found papers	Selected # papers	Precision
roasting coffee quality	AND AND AND	SCIENCEDIRECT	157	100	63,7%
assessment Electronic eye Nose tongue	OR AND/OR OR/AND OR/AND OR/AND	IEEE	27	10	37%
		SCOPUS	120	71	59,2%
		EBSCO	30	14	46,7%
subtotal			334	195	
Duplicate				23	
Total				172	

Figure 2 shows the flowchart of the systematic literature review process. From 195 papers and removing the duplicates obtained a total of 172 articles for systematic review.

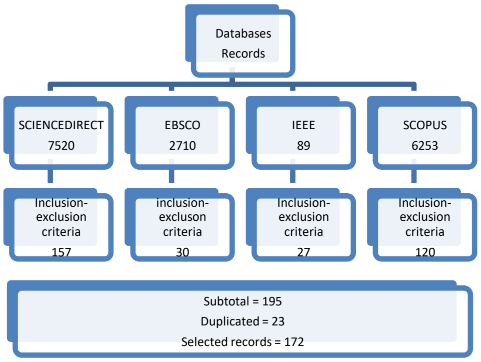

Figure 1. Flowchart of the systematic review of the literature

In this way, the most relevant topics of the review were condensed, based on the keywords found in the analyzed documents. Among them were studies that show the physicochemical characteristics of green coffee and roasted coffee, as well as investigations of the complexity and defects of coffee and instruments for measuring organoleptic characteristics of coffee established by the SCA. Following this, we found the inclusion of non-invasive evaluation technologies such as the electronic nose, eye, and tongue electronic, as support tools for tasters in their need to generate broader analysis, involving the desired perceptions and characteristics, now obtained from electronic sensors that complement the understanding of the processes that occur in a roasted coffee bean.

Additionally, five topics of interest were created, described in Table 2 as working groups, highlighting the number of articles that refer to the topic and their percentage weight in the review.

Table 2. Cluster information for review in topics of scientific interest.

Topics	# papers	weight %
Physicochemical characteristics of roasted coffee	80	41%
Cupping evaluation for quality control purposes	24	12,3%
Electronic Nose and tongue for quality assessment	40	20,5%
Sensors for product characterization.	25	12,8%
Hybrid systems for fusion of data collected from sensors	26	13,3%
Duplicate	-23	
Total	172	100%

Network Concepts in coffee quality analysis.

With the information selected in the previous step, the systematic concept design was constructed, whose objective is to confront the techniques used for the evaluation and characterization of the attributes of roasted coffee and the current perspectives in the field of hybrid systems as support tools in the coffee value addition chain. Its structure is shown in Figure 3.

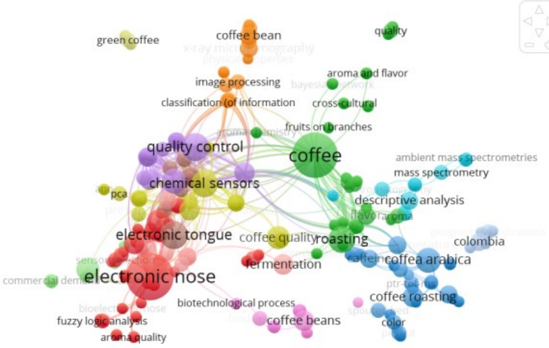

Figure 2. VOSviewer Network Map of systematic mapping of concepts.

Currently, advances in food quality inspection, evaluation and analysis systems have focused on Industry 4.0 for food products (Afoakwa, 2016; D. C. Costa et al., 2015; Dunkel et al., 2014; J. Gutiérrez & Horrillo, 2014; Jackson, 2008; Le Quéré, 2010; Nolvachai et al., 2017; Steinhart et al., 2000) The ideal coffee production process, for example, should be a predictable and continuous process, similar to that of the automotive industry; This is not possible for the coffee industry, since each process of harvesting, processing, roasting and storage is different, and influences the quality of the final product (NEUHAUS NEOTEC, 2017) The industrial automation of the coffee process is being interrupted by sensory analysis, which must be done by an expert human taster, before and after the roasting process, to evaluate and monitor quality. The coffee roasting process is the focus of current research and development, as this is where the greatest added value to coffee is generated (NEUHAUS NEOTEC, 2017) Se have contributed previous studies and research to categorize odors, identify the volatile compounds of coffee, determine its roasting level, decode its flavor and reconstruct its aroma (Borém et al., 2013; Castro et al., 2013; Paulo R A B de Toledo et al., 2017; Ferreira et al., 2016; Puerta Quintero, 2016; Ribeiro et al., 2012; Rodrigues et al., 2012; A. F. L. O. M. Santos & Ribeiro Da Silva, 2011; Toshio et al., 2009) and it still represents a challenge to integrate these instrumented systems for sensory analysis (vision, smell and taste), as a support tool for the panel of tasters, in general for all actors in the specialty coffee chain (NEUHAUS NEOTEC, 2017)
Coffee has its own characteristics that are taken into account for quality control, such as origin (Puerta Q et al., 2016) bean size, yield, density, humidity, water activity, color (Borém et al., 2013; Correa et al., 2011; E. M. De Oliveira et al., 2016; Suslick et al., 2010; X. Wang & Lim, 2015b) texture (Guevara Barreto & Castaño Castrillón, 2005) roast profiles, roasted coffee color, fragrance, aroma, flavor, body, acidity, clean cup and uniformity (Alessio et al., 2016; Brudzewski et al., 2012; S Buratti et al., 2017; Mendez, 2016; Romani et al., 2012; Sberveglieri, Pulvirenti, et al., 2014; Várvölgyi et al., 2012, 2013) These characteristics must be measured, either by physical, chemical and / or microbiological means, to exercise quality control strategies, and for this purpose artificial vision systems, noses and electronic tongues have been developed and implemented, which provide alternative solutions to these measurements, raising in advance the possibility of opening a field of study in the evaluation of perception systems biomimetic sensory, which accompanied by data processing methods and multivariate signals of analysis constitute novel tools for inspection and why not for quality diagnosis (Apetrei et al., 2010; Susanna Buratti et al., 2018; Fitzgerald et al., 2017; Ghasemi-Varnamkhasti et al., 2010; Lvova et al., 2015; Mendez, 2016).

Electronic instrumentation in the food industry

The most widely used industrial instrumentation systems for the sensory analysis or diagnosis of food quality have been colorimetry techniques, and electronic nose and tongue systems; systems that transform a sensory perception originated by the sample, into indicators, from electrical, magnetic, chemical, thermal or electromagnetic radiation signals (Askim & Suslick, 2017; Banerjee et al., 2016; Castro et al., 2013; Colzi et al., 2017; Fitzgerald et al., 2017; Ishiwaki, 2013; Mendez, 2016; Oliveri et al., 2010; Śliwińska et al., 2016). Currently, gas sensors, electrochemical electrodes and optical or spectroscopy techniques have been used to evaluate and quantify the sensory characteristics of coffee, as promising techniques for the systematic evaluation of quality (Ruiz-Altisent et al., 2010) The choices of these systems are related to aroma, taste, and color and hue parameters, respectively (Susanna Buratti et al., 2015; Magdalena et al., 2014) E-Eye systems, for example, have been proposed for the evaluation of the quality of coffee products, through extraction of color characteristics, using colorimetry and image processing, including the hyperspectral technique(Cho et al., 2017; Gabriel-Guzmán et al., 2017; Ma et al., 2017; Nansen et al., 2016; Oblitas Cruz & Castro Silupu, 2014; Portugal-Zambrano et al., 2017) Systems based on E-Nose and E-Tongue, which have been widely used for fruit juice recognition (Haddi et al., 2014; Peris & Escuder-Gilabert, 2013)beer discrimination (Ceto et al., 2013; J. M. Gutiérrez et al., 2013)inspection of fermentation and aroma in wines (Bakker & Clarke, 2011; Policastro et al., 2007; Sáenz-Navajas et al., 2016)the quality and aroma of tea (Banerjee(Roy) et al., 2014; Chen et al., 2015; Dai et al., 2015; Dutta et al., 2011; Shi et al., 2013; Tudu et al., 2015) Likewise, important properties of sunflower oil (Upadhyay et al., 2017)the taste and aroma of saffron (Kiani et al., 2016a)the attributes of the potato (Chatterjee et al., 2014; Sundic et al., 2000)the quality of cocoa (Tran et al., 2015)bananas (Sanaeifar et al., 2014) importantly in the identification of defects and sensory attributes of coffee products (Bona et al., 2011, 2016; Radi et al., 2016; Rodríguez et al., 2010; Ruiz-Altisent et al., 2010) All these contributions contributed to applying these techniques to identify some variables that influence the organoleptic properties such as the volatile organic components of the aroma and the chemical elements that represent the flavor, aimed at training and continuous updating of expert tasters. Next, the advances in the identification of quality indicators for roasted coffee, using the techniques already mentioned and their relationship with the protocols of preparation and tasting of roasted coffee are highlighted.

Discussion

Color indicators for roasted coffee: The electronic eye (E-Eye)

Roasting is the most important step in coffee processing, responsible for the chemical, physical, structural and organoleptic changes in the bean(X. Wang & Lim, 2015a) During this process the green and dry grains are subjected to a treatment characterized by several temperatures applied in different phases over time, which will determine the final characteristics of the product. The color is the most used parameter to establish the level of roasting of the coffee, a relevant aspect at the time of evaluating the quality of the final product. For color measurement in coffee, there is specific instrumentation such as commercial colorimeters developed exclusively for this application. (Puerta Quintero, 2016). Experimentally, the type of light, medium or dark roasting has a definitive impact on quality and is also associated with consumer preferences(Gloria Puerta, 2009) The darker the roast, the less pronounced the acidity and different flavor aspects (and defects) of the drink, but the more consistent the body (Gloria (Gloria Puerta, 2009) The lighter the roast, the more pronounced the acidity and taste (and defects), but the body is lighter. Taking into account the above, it has been detected that in the roasting industries, where green coffee beans are required, several parameters can be used as quality indicators of the degree of roasting: the aroma, flavor, temperature of the bean, pH, chemical composition, loss of mass, and fundamentally the color and hue (Ruiz-Altisent et al., 2010; Vargas-Elías et al., 2016; Wu & Sun, 2013)

The relationship of color and organoleptic characteristics of cup coffee is established by expert tasters, who define the color descriptors according to the SCAA protocol, for each relevant quality attribute, among which the tones of the Agtron Gourmet Scale, of the American Specialty Coffee Association (SCAA), which goes from No. 95 (the lightest roasting), stands out. at intervals of 10, up to No. 25 (the darkest common roast)(SCAA, 2015)(Gloria Puerta, 2009) The AGTRON system uses eight numbered color discs, with the reference described above, with which the sample of finely ground and roasted coffee, usually crushed on a Petri disc, is compared. In this way, roasted coffee is assigned the approximate number on the SCAA scale. This information is highly subjective, despite the preparation and experience of the roaster, and is used to generate the roasting curves, manually or automatically, and thus achieve the desired coffee. In this sense, the most relevant question in research for this field has been What is the optimal tone and intensity level of a roasted coffee?. This question has admitted several answers depending on the habits and tastes of the market to which the final product is directed. Different manufacturers roast coffee differently, in this way, they must know what kind of roast their buyers need, and this is how the expressions "light, medium and dark" mean different things to different people and therefore are subjective terms (SCAA, 2015)(Gloria Puerta, 2009)

The AGTRON/SCAA scale allows producers and roasters to use the same language when talking about the "roasting" of a coffee. However, this language incorporates subjectivity, especially when in the evaluation of a roasted brown machine, the lighting is not controlled, two different shades can be found for the same coffee, which causes a difference in the color perception of that coffee sample. The latest studies in colorimetry have striven to integrate the measurement of color and hue parameters, both of roasted coffee, and of the SCAA Agtron measurement discs, in their standardized scale, contributing to the quantification of the levels of roasting that they throw and their corresponding instrument, this information is presented in Table 4 (Diezma & Cristina, 2011).

Table 3. Equivalence of colorimeters for coffee on the Agtron/SCAA gourmet scale. Taken from (Diezma & Cristina, 2011)

Evaluation	QUANTIK	MINOLTA (L)	PROBAT	SCCA/ AGTRON
Very dark	100	13	43	25
Very dark	101	13.04	56	35
Dark	139	14.43	56	35
Dark medium	173	15.83	69	45
Middle	202	17.22	85	55
Medium Light	228	18.66	95	65
Light	269	21.24	108	75
Very light	330	29.32	121	85
Very light	349	31.09	134	95

The colorimetric study has focused on quantitatively determining the level of roasting of coffee based on color, however, the study of the variability that exists in the final evaluation of coffee quality is not addressed, given that there are nuances, for example, between the middle colors, 55 or 65, of the discs of the Agtron/SCAA scale, Figure 4, generating fluctuation in the diagnosis of the expert taster in account of the perception of color in an uncontrolled lighting environment (Diezma & Cristina, 2011) Meanwhile, the determination of the color of the middle tones, where they obtain the best organoleptic attributes of coffee, is currently the subject of research in this field (Federación Nacional de Cafeteros, n.d.).

COLOR	Agtron disc # tile	SCAA	L	a*	b*	HUNTERLAB spectral reflectance (650 nm)	(C,M,Y,K)
■	**25**	**Very Dark**	14,7	4,31	4,41	2,54	**(0,23,32,82)**
■	**35**	**Dark**	14,85	6,15	5,87	2,43	**(0,30,40,81)**
■	**45**	**Moderately Dark**	18,23	8,77	9,71	3,66	**(0,35,49,76)**

🟫	**55**	**Medium**	22,07	10,94	13,01	6,58	**(0,37,54,71)**
🟫	**65**	**Light Medium**	25,45	12,31	17,59	8,19	**(0,38,60,67)**
🟫	**75**	**Moderately Light**	28,1	13,1	20,53	9,71	**(0,38,62,63)**
🟫	**85**	**Light**	30,15	13,55	22,86	11,28	**(0,38,64,61)**
🟫	**95**	**Very Light**	32,45	13,04	23,48	12,81	**(0,36,62,59)**

Figure 3. Numbering and color of Agtron discs of the SCAA gourmet scale

Table 4 shows the summary of the most used sensory evaluation references of coffee, where it is evident that this correlation for the evaluation of coffee quality, based on color, still has research gaps and suggests a technological intervention to take advantage of the significant differences and great potential that the study of E-Eye systems has (Federación Nacional de Cafeteros, n.d.), especially to exploit the different shades of color which may represent a sample of coffee with exceptional organoleptic properties and which are currently condensed into subjective terms commonly used in coffee roasting. Although modelling studies of physical properties such as grain size, density, humidity and water activity have been carried out in relation to heat transfer processes, the chemical mechanisms that give way to color variability throughout grain volume are still unknown (Fabbri et al., 2011) From a quantitative point of view, the color of roasted coffee is not yet a quantifiable indicator of quality, because, although the coffee seems roasted on the outside, it could be raw inside; this is due to the density of the bean and its homogeneity in size at the time of roasting. Currently, the color of roasted coffee can be offered to the consumer as a measure of transparency of the entire roasting process and currently colorimeters are used that show values associated with the experience and taste of consumers in the process of making beverages. Table 4 shows the references of roasted coffee color related to the barism experience and consumer preferences.

Table 4. Referents of color and roasting level on the SCAA/AGTRON scale. Modified from (Diezma & Cristina, 2011)

ROASTED	CHARACTERISTICS OF COFFEE
Very light	Color 95 grass aroma, not developed
Light	Color 85 little intense aroma, taste not fully developed.
Moderately light	Color 75 soft aroma, acid, original taste of the product, light body. Not appropriate for espresso.
Medium light	Color 65 intense aroma, bitter expressions are felt, but maintains balance.
Medium	Color 55 more intense aroma, maintains a good balance
Medium high	Color 45 very intense aroma, but losing nuances. It is bitter, tall body.
Dark	Color 35 Notice somewhat burnt aromas and pronounced bitter tastes, loses acidity, but can work well in places where you like strong coffee.
Very dark	Color 25 loss aroma, gives off many oils, the taste is clearly burnt.

The electronic nose (E-Nose)

Another important factor in the coffee quality assessment protocol of the SCA, is the analysis of aroma and fragrance of coffee, these are also carried out by the panel of experts in a slow and expensive process, since it requires acute sensory experiences of tasters, who are increasingly trained to work on breaking down the smell, aroma and fragrance of coffee, but being affected by the wear and tear of the human condition, and its olfactory system requires longer periods of time, through high repetitions, to perceive the olfactory expressions of the volatile organic compounds of coffee, which represent quality in the SCA protocol (Feria-Morales, 2002; Kiani et al., 2016b). Commonly this evaluation is affected by the level of fatigue of the panel of tasters, their state of health and the number of repetitions that affects their ability to evaluate.

In this sense, electronic smell systems (E-Nose) of different types have been proposed, including those that use sensors based on Metal Oxides (MO_{x}),conductive polymers or field effect transistors and biosensors (Park, 2014) The data extracted from these devices have been treated through multivariate data analysis and artificial intelligence and it is reported that they have been able to measure and characterize volatile organic compounds with applications in health for disease detection, military security, for the detection of explosives and drugs (J. Gutiérrez & Horrillo, 2014; X. Zhang et al., 2018a). Table 5 presents some of the sensors that have been used over the years.

Table 5. Main sensors used in Electronic Nose. Modified from (Banerjee et al., 2016)

Topology	Class	Fundamental	Measurement	Sensor type
Direct	Physicists	Electrical Conductance	Conductance	Chemical-resistive (CP)(Conductive polymer)
		Capacitive	Capacitance	Chemical Capacitive-polymer
	Chemistry	Amperimetry	Current	Toxic gas - electrocatalytic
		Chemical Conductance	Conductance	Resistive Chemical – MOS (Metal Oxide Sensors)
		Potentiometric	Voltage e.m.f	Diode chemist – Schottky diode
			I-V/C-V	Transistor Chemist – MOSFET (MOS-based Field Effect Transistor Sensor)
Complex	Physicists	Gravimetric	Piezoelectricity	Mass Sensitive Chemical-QCM (Quartz Microbalance Sensor)
				Mass Sensitive Chemical-SAW (Surface Acoustic Wave Sensor)
		Optical	Intensity /Current	Fiber optic chemist, fluorescence, chemiluminescence
	Chemistry	Calorimetric	Temperature	Thermal chemist, thermistor, thermocouple
		Amperimetry, thermal, optical	Current, temperature, light intensity.	Biosensors (organisms, tissues, cells, enzymes, antibody)

According to this information, contributions and studies have been found to address the problem of the application limitations of these sensors in the coffee industry, due to their low sensitivity to volatile organic compounds (VOCs) (Patel et al., 2014) For example, sensors have been developed that increase sensitivity to VOCs, from parts per million (ppm) to parts per billion (ppb) compared to the human one that can distinguish up to parts per trillion (ppt) (Berna, 2010; Omatu et al., 2015; Patel et al., 2014) A system that uses OR's odor receptors (Olfactory Receptors) as a sensor element, is reported in the literature as Bioelectronic Nose, built with odor receptor proteins combined with sensor elements that allow interpreting the biological signal in electronic or optical signals and constitutes the latest advance in this topic for the selectivity and sensitivity of odors (Son et al., 2017; Wasilewski, Gębicki, et al., 2017; X. Zhang et al., 2018b). Electronic noses find their application in reports of the evaluation of coffee quality, for the identification of the most representative volatile organic compounds of coffee, discriminate between three types of commercial coffee, analyze data from chemical and physical sensors to determine the aroma of coffee, quality control of green coffee beans and in the evaluation of coffee quality, through the identification of olfactory defects of the green grain (Brudzewski et al., 2012; Cole et al., 2011; Rodríguez et al., 2010; Tan et al., 1997) Volatile organic compounds VOC and non-volatile, which are found in greater concentration and offer greater development of the expression of flavor, aroma, fragrance and softness to coffee, are shown in Table 6.

Table 6 Chemical groups of some aromatic notes of roasted coffee. Taken from (Caligiani et al., 2008; G Puerta, 2011; Sims & O'Loughlin, 1989; Aline T Toci & Farah, 2008; Yang et al., 2016)

Furans: Caramel, straw, grass, sugar, burnt, smoked almond, astringent, fruity.	**Pyrazines:** Corn, earth, moldy, walnut, corn, tar, fatty, paprika, peanut, rancid.	**Oxazoles:** Almond, legumes, sweet, hazelnut, earth, green potato
Ketones: Butter, caramel, sweet, honey, fruit, cooked apple, rancid fat, wood.	**Thiophenes:** Onion, mustard, fetid.	**Pyrrols:** Sweet, corn, cereal, oil, medicinal, edible mushrooms, fat, walnut.
Esters Fruity, sweet, fatty, rancid, irritating, floral.	**Phenols:** Tobacco, smoked, clove, phenolic, burned, astringent rubber, bitter, spicy, earthy, wood.	**Pyrans:** Sweet, eucalyptus.
Acids: Vinegar, sweet, rancid, floral, menthol, fruity, green, herbal, fatty, rancid, moldy, earthy.	**Amines:** Unpleasant, intense, decomposed, fish, ammonia.	**Aldehydes:** Wine, honey, cooked, toasted, fat, green wood, malt, acid, fermented, sweet spicy, herbal, cooked potatoes, fruity, vanilla, spicy, burnt, rancid
Thiols: Aged, decomposed, animal, roast meat	**Hydrocarbons:** Fetid, petroleum, butter, earthy, wood	**Lactones:** Peach, coconut, walnut, sweet, spice, burnt, fat
Pyridines: Bitter, astringent, caramel, butter	**Thiazoles:** Earth, green potato, nuts.	**Alcohols:** Floral, sweet, fruity, moldy, earthy, toasted, green, herbal, rancid.

The aromas developed in the coffee bean are composed of several volatile substances (VOCs) and that is why olfactory sensations are not easy to describe, classify and quantify, since there is no scale of smell, such as that of sounds or electromagnetic waves (G Puerta, 2011; Yang et al., 2016) In general, smells are described with analogies such as, smells of roses, meat or is a sweet smell, chamomile or mint. Each person has different sensitivity to odors and, therefore, partial information is obtained about the quality of the product. Thus, from the instrumental point of view, sensors have been developed to detect mainly compounds such as alcohols, hydrocarbons and mixture of them, providing a series of data, to be analyzed and converted into descriptors for the identification and quantification of aromas (Caligiani et al., 2008; Yang et al., 2016; Zajdenwerg et al., 2011) Table 7 presents a consolidated status of the sensors most commonly used to detect volatile organic compounds VOCs. The detection fractions do not demonstrate identification, properly speaking, of each component, since it only represents a variation of a resistive system due to the presence of a mixture of gases in its proximity. This resistive technique has limitations in sensitivity and its relationship with the generation of heat by joule effect, allows acceptable performances. In this sense, gas sensor arrays have been proposed, such that, by statistical methods and neural networks, they manage to generate a classification of the components of a gas present in a controlled volume.

Table 7. Most used commercial sensors for VOC and air quality detection.

Manufacturer Winsen	Gas detected	Manufacturer Figaro	Gas detected	Sensitivity (ppm)
MQ-2	CO_2	TGS2600	H_2, CO and VOCs	1-30
MQ-3	Alcohol	TGS2620	VOCs	1 -30
MQ-4	Natural gas, methane	TGS2611	VOCs	500-10000
MQ-5	LPG, natural gas, coal gas	TGS2610	VOCs	500-10000
MQ-6	LPG, propane	TGS822	VOCs	500-10000
MQ-7	Carbon monoxide (CO)	TGS2602	VOCs	50-5000
MQ-8	Hydrogen	TGS821	H_2	5-100
MQ-9	CO and Fuel Gas	TGS4161	CO2	350-10000
MQ303	Alcohol	TGS826	NH_3	30-300
MQ131	Ozone O_3	TGS2201	NO and NO_2	0.1-10
MQ135	Air quality control (NH_3, Benzene, alcohol, smoke)	TGS800	Air quality, smoke, benzene	50-5000
MQ136	Sulphur hydrogen (H_2S)	TGS825	H_2S	10-1000
MQ137	Ammonia (NH_3)	TGS826	Ammonia	30-300
MQ138	VOC (aged, benzene, aldehyde, ketone, ester)	TGS2444		10~300

Sensor technologies are categorized according to their sensitivity, and have been used to identify defects in a cup of coffee (Cole et al., 2011; Rodríguez et al., 2010; Sberveglieri, Núñez, et al., 2014)revealing the importance of continuing this study (Patel et al., 2014; Pearce et al., 2016; Thepudom et al., 2013)using various sensor arrays (Kiani et al., 2016a) Designs of bioinspired sensory perception environments have also been proposed that aim to integrate the effects and phenomena that occur in the human nasal cavity (Fitzgerald et al., 2017) In this sense, other hybrid systems have been developed that are projected as valuable elements for the classification of as many sensory attributes as possible, in favor of obtaining valuable information, both for the training of human tasters and to generate integrated capabilities to the use of new technologies for the evaluation of the aroma and fragrance of the coffee. (Bona et al., 2016)

The Electronic tongue (E-Tongue)

E-Tongue electronic taste systems have been widely used to discriminate the 5 basic flavors: salty, sweet, sour, bitter and umami(Rattanawarinchai et al., 2017; Tahara & Toko, 2013; Yasuura & Toko, 2015) The sweet taste that makes secrete a thick and viscous saliva, and is perceived mainly at the tip of the tongue by the fungiform papillae(Gupta et al., 2010) The bitter taste is very sensitive to the taste buds, located at the back of the tongue(Gupta et al., 2010) The acidic taste is felt most intensely at the middle lateral edges of the tongue and also at receptors located on the mucosa of the lips and on the veil of the palate(Gupta et al., 2010) The salty taste is felt in all parts of the tongue and especially in the lateral and front areas of the tongue(Gupta et al., 2010) Other taste sensations are freshness, spiciness, astringency, metallic and umami (Monosodium glutamate)(Sung et al., 2017) Thus, the subjectivity in the sensory perception of a taste is high, and is technically related only to a person's experience when tasting a food and engraving in his memory a memory of the sensation. In contrast to this, electronic tongue systems or E-Tongue, based on flavor sensors, have been developed, taking into account five major typologies: optical, electrical, biosensors, electrochemicals and gravimetric(Banerjee et al., 2016) It is necessary to include differentiation in the terminology used in English, since the term "flavor" is a complex term that implies sensory perception of all the senses, the effect of sight, touch, hearing and smell, in addition to taste, on food. On the other hand, the concept of “sabor”, in Spanish, refers to the basic favors that we perceive in the tongue (acid, sweet, bitter, salty and umami).
In particular for coffee, E-Tongue systems are based on electrochemical sensors built as glass electrodes containing lipids and special membranes, which in the presence of acids, bitter, salty substances and using the special integration of umami, throw an electrical signal that is associated with the presence of large groups of chemical compounds (Gupta et al., 2010). Application of electronic tongues has been found to discriminate the levels of some of the most relevant components of coffee (Alessio et al., 2016; A. M. S. Costa et al., 2014; Várvölgyi et al., 2012, 2013) especially when the levels of compounds such as caffeine and chlorogenic acid have been quantified. According to these studies, the sensory expression of coffee can be described as: caramel, chocolate, delicate, earthy, fruity, sweet, winey, almond, spicy, dirty, soft, sour, rancid, rough, watery, balanced, ferment, phenol, smoked among others. Coffee contains several alkaloids that contribute to the bitter taste of coffee such as caffeine, trigonelin and others in lower concentration such as paraxanthin, theobromine and theophylline. On the other hand, chlorogenic acids correspond to many hydroxycinnamic phenolic acids, mainly the cynical acid of quina and coffee; cinnamon and peanuts; the synapic of broccoli, cabbage and green leafy vegetables; cumens from peanuts, carrots, tomatoes and garlic; the ferulic of oats, cereals, apple, beets and oranges; the caffeic of blueberries, apple, citron, oregano, verbena, thyme, basil, turmeric, dandelion, olives and coffee; chlorogenic or caffeoylquinic (CQA) which is the most abundant in coffee and is also found in blueberries and apples; and the dicaffeoylquinics (di-CQA) of artichoke, chicory and sunflowers. The components that present the most variability in roasted coffee and coffee drink are chlorogenic acid and caffeine. These two compounds have been the subject of various studies and especially voltamperimetric techniques have been used to quantify the concentration of these substances and thus apply this tool to, for example, discriminate between varieties of coffee, evaluate their quality and authenticity, through the chemical composition of a cup of coffee (Mendez, 2016; G Puerta, 2011). It is evident that there is a large field of research in this area, given the variety of characteristics and attributes that are assigned to the sensory perception of coffee, which makes it possible to study the complex components of coffee (Sunarharum et al., 2014) remains to be investigated of each of the factors that affect the evaluation of coffee quality, through olfactory sensory perception, taking into account the most relevant compounds, among these those shown in Table 8.

Table 8 Most relevant components for the taste of coffee. Taken from (G Puerta, 2011)

Compound	Function in the Coffee Drink
Polysaccharides	Retain aromas, contribute to the body of the drink and espresso foam
Sucrose	It gives the bitterness, taste, color, acidity and aroma to coffee.
Reducing sugars	They contribute to the overall color, flavor and aroma.
Lipids	They transport the aromas and flavors of coffee. In espresso they give flavor and body.
Proteins	They contribute to the bitter taste. In espresso it forms the foam, according to the degree of roasting.
Caffeine	They contribute to the bitterness of coffee.
Trigonelin	It contributes to the bitterness and the products of its degradation to the final aroma of coffee.
Chlorogenic Acids	They give body, taste, bitterness and astringency to the drink (bitterness and dryness).
Aliphatic acids	Acidity, body, aroma in general.

The most used commercial sensors to detect these substances and compounds, which represent a taste, are consolidated in Table 9. Electronic tongue aims to discriminate and analyze food and beverages using sensor arrays such as ion-selective electrodes with different specificity properties and statistical analyses such as PCA and neural network techniques. On the other hand, the flavor sensor that uses a lipid polymer membrane was developed to realize a sensor that responds to flavor chemicals and can be used to quantify the type of taste, focusing on the fact that humans discriminate the taste of food on the tongue. Samples can be discriminated if the five basic tastes can be discriminated against and quantified (Tahara & Toko, 2013)

Table 9. Sensor components for basic flavor. Taken from (Tahara & Toko, 2013)

Taste	Lipid	Plasticizer
Salty	Tetradodecylammonium bromide n-Tetradecyl alcohol	Dioctylphenylphosphonate
Acid	Phosphoric acid di(2-ethylhexyl) ester, Oleic acid, Trioctylmethylammonium chloride	Dioctylphenylphosphonate

Umami	Phosphoric acid di(2-ethylhexyl) ester, Trioctylmethylammonium chloride	Dioctylphenylphosphonate
Bitter sour	Phosphoric acid di-n-decyl ester Bis(1-butylpentyl) adipate	Tributyl O-acetylcitrate
Basic bitter	Tetradodecylammonium bromide	Dioctylphenylphosphonate
Astringent	Tetradodecylammonium bromide	2-Nitrophenyl octyl ether
Sweet	Tetradodecylammonium bromide, Trimeritic acid	Dioctylphenylphosphonate

Hybrid systems

From the point of view of human sensory perception, one cannot isolate the sense of smell from the sense of taste, as they represent a unity when it comes to defining a taste and aroma, and vice versa. In recent studies, various hybrid systems have been tested, which seek the integration of odor, taste and aroma descriptors quantitatively(S Buratti et al., 2017; Ghasemi-Varnamkhasti et al., 2010; Haddi et al., 2014; Hong & Wang, 2014; Mendez, 2016; Śliwińska et al., 2016). At the conclusion of this research, a scheme has been developed to demonstrate the importance of the hybrid systems E-NOSE and E-TONGUE, to potentially emulate the sensation of memorizing a complex flavor, composed of sensations of aroma and basic flavor, as shown in Figure 5.

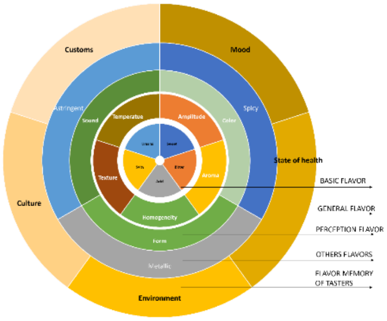

Figure 4. Integration of the sense of smell and taste for coffee.

Figure 5. Wheel of flavors and aromas for coffee.

According to the above, studies have been found on the application of electronic tongue in favor of discriminating some of the flavors described in the flavor palette for coffee (Alessio et al., 2016; A. M. S. Costa et al., 2014; Várvölgyi et al., 2012, 2013)based on the SCA building a system of wheels of flavors and aromas that group a whole profile of perceptions for coffee, as shown in Figure 4. In this wheel you can see all the standardized aromas and flavors and for which electrochemical sensors were designed based on the compounds related in Table 7, which could measure the electrical potential of a coffee solution and thus perceive its flavor expression components, which represents a great potential of application to contribute to the evaluation of coffee quality. On the other hand, hybrid electronic systems are based on data analysis algorithms, particularly the analysis of PCA principal components, artificial neural networks and data fusion implemented for, for example, the identification of food and beverage authentication and quality assessment (Banerjee(Roy) et al., 2014; Borràs et al., 2015; J. M. Gutiérrez et al., 2013; Kiani et al., 2016c; Singh, 2002). Although most of these initiatives study the fusion of electronic nose and tongue data, other proposals go further, integrating computer vision techniques(Apetrei et al., 2010; Susanna Buratti et al., 2018; A. R. Di Rosa et al., 2017; Ghasemi-Varnamkhasti et al., 2010; Ruiz-Altisent et al., 2010; Várvölgyi et al., 2014) Susana Burati's most recent study uses hybrid systems, and reports a very promising tool for olive oil characterization and quality assessment using a date fusion approach of the E-Nose, E-Tongue and E-Eye systems(Susanna Buratti et al., 2018) This last type of system would allow to obtain data from different sources, as does a human expert, and then merge them to obtain information that generates a global description of the analyzed product, taking into account the definition and appropriate selection of the descriptors or markers for each perception, using as a data processing technique. Commonly used multivariate pattern analysis techniques are presented in Table 10.

Table 10. Multivariate Pattern Analysis Techniques. Modified from (Banerjee et al., 2016)

Typology	**Type of Analysis**	**Category**	**Type of algorithms**
Electric and statistical chemometric	Quantitative		Multiple linear regression
			Partial least squares
	Pattern analysis	Unsupervised	Clustering
			Principal Component Analysis
		Supervised	Principal component regression
			Discriminant function analysis / Linear discriminant analysis
Biologically Inspired **biomimetic**	Artificial neural networks	Unsupervised	Self-organized maps
		Supervised	Multilayer percepctron
			Probabilistic neural networks
			Radial base function networks
			Quantification of the learning vector.
	Fuzzy logic methods	Self-monitored	Adaptive resonance theory
			Fuzzy logic with art maps
		Supervised	Fuzzy inference systems
			Diffuse neural networks
			Diffuse groupings
	Other	Self-monitored	Genetic algorithms
		Supervised	Neurodiverfused system
			Wavelets

Data fusion in food quality assessment is not new(D. L. D. L. Hall et al., 1997; D. L. Hall & Llinas, 2008)since industrially multiple sensors are combined to achieve more precise inferences about the product and guarantee safety and quality of the product (Borr??s et al., 2015; Dong et al., 2017; Haddi et al., 2014; Kiani et al., 2016c). The current challenge is how to significantly acquire only individual variables of quality characteristics, but by blocks of them (e.g. NIR spectra and UV-vis spectra), through an analysis, complementary, redundant or cooperative (Dong et al., 2017) Today, analytical laboratories commonly have instruments that can be used successively to analyze the same sample. Multivariate statistical analysis of the fused data of these techniques can be a powerful tool for reliable results.

Finally, Table 11 presents the relationship found between the criteria and the research questions in the topic of data analysis and electronic instrumentation for its application in the value chain of specialty coffee.

Table 11. Trends, prospects, and challenges posed for coffee research.

Research Questions	Criterion	Possible answer	Results	
			Number of studies	% of studies
RQ1: What techniques have been used to identify and classify coffee according to its origin, variety, benefit, value addition and sensory profile?	C1: Conventional techniques	Training - Sensory Profiling - SCAA	21	12%
	C2: Protocols	Q processing program	14	8%
	C2: Computational techniques	Descriptive statistical methods and image processing	12	7%
RQ2: What is the relationship and importance between the degree of roasting of coffee and the sensory attributes of fragrance, aroma, acidity, bitterness, body and global expression?	C3: Roasting curves	HTST: high temperature short time profiles	15	9%
		LTLT: low temperature long time profiles	11	6%
		Roasting profile with consistency	5	3%
RQ3: What techniques have been used to identify the aroma and flavor components of roasted coffee?	C4: Tools for the analysis of physical properties, volatile and non-volatile organic components.	Electronic eye with multifactor analysis	15	9%
		Electronic nose with multifactor analysis	11	6%
		Electronic tongue with multifactor analysis	8	5%
RQ4: What are the non-trivial techniques for determining the color, smell and taste of roasted coffee, applied to the quality evaluation of the same?	C5: Multivariate Pattern Analysis Techniques	Chemometry and statistics: Multiple linear regression	5	3%
		Partial least squares	8	5%
		Clustering	5	3%
		Principal Component Analysis	10	6%
		Principal component regression	6	3%
		Analysis of the discriminant function	2	1%
		Linear discriminant analysis	4	2%
		Biomimetics: Multilayer percepctron	2	1%
		Probabilistic neural networks	2	1%
		Radial base function networks	1	1%
		Quantification of the learning vector	1	1%
		Adaptive resonance theory	1	1%
		Fuzzy logic. Fuzzy inference systems	1	1%
		Diffuse neural networks	2	1%
		Diffuse groupings	2	1%
		Genetic algorithms	4	2%
		Neurodiverfused system	2	1%
		Wavelets	2	1%
Total			**172**	**100%**

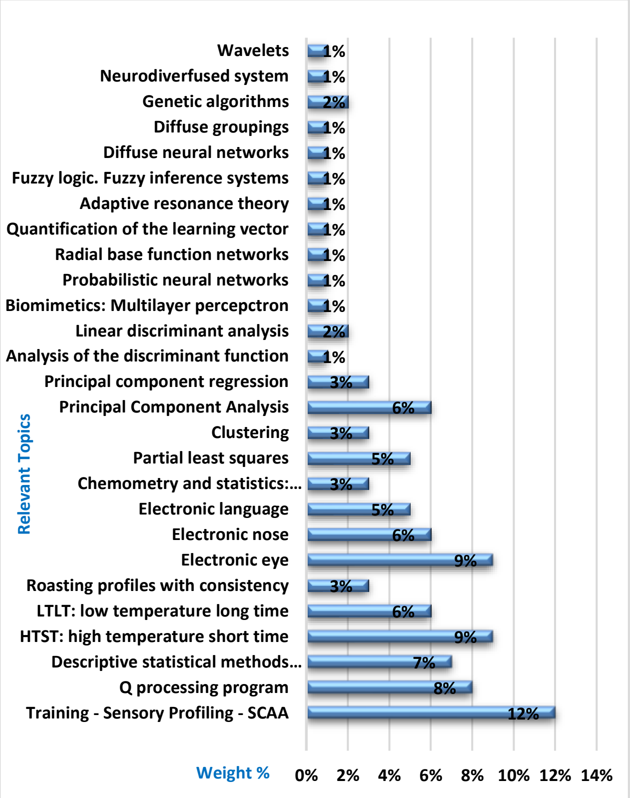

Figure 6. Analysis of trends, prospects and challenges posed for research in Coffee.

There is a growing and greater contribution in training, calibration, and recalibration in SCA protocols with 12% of the total studies. Followed by the tendency to studies HTST (High Temperature Low time) roasting curves with 9%, related to grain density and collect as much information as possible on how to reduce or prolong roasting time and its effect on the final organoleptic properties. Similarly, the electronic eye with 9%, whose work has been done seeking to define the color of roasted coffee as an indicator of quality, transparency, and traceability in the process, using electronic instrumentation as quantitative support of this perception. With 8% was the Q-PROCESSING (General, professional, and expert) training program, which provides knowledge with a scientifically founded basis to understand and communicate about coffee processing and its contribution to improving the quality of the raw material.

It should be noted that the statistical methods are transversal to the tools and that descriptive statistics were particularly found with 7% and the analysis of main components with 6%. These elements were key to supporting the coffee studies that were reviewed. More precisely in roasted coffee, it was found that the LTLT (Low Temperature Long Time) roasting curves yielded strong data that affected the quality of roasted coffee, but that are not yet conclusive, due to the variant factors of the coffee batches in each roast.

As a fundamental part of the quality analysis, the electronic nose was found with 6% and the electronic tongue with 5% of the total of the studies, as an unconventional instrument is to integrate quantitative data of the intensity with the hedonic data of the perception of coffee obtained both by an expert taster and by a common person. Finally, a very interesting panorama is shown to include data analysis tools from instrumented systems such as the nose, eye and electronic tongue integrated into biomimetic multivariate processing techniques and metric chemo that have a potential for current application and that can be democratized at different scales of the coffee value chain.

Conclusions

This review reports the relevant characteristics between electronic instrumentation and quality analysis of specialty coffee. Despite the various topics worked on in the coffee process, the differences and integration of each of the technologies of the eye, smell and electronic taste were shown. Among the results of the selected studies, some common elements were found, including the fusion of the senses for the descriptive sensory evaluation of coffee qualities. Therefore, in the studies of electronic nose E-Eye and electronic tongue E-Tongue the experimental use of them has been increasing or tending to increase their degree of fusion to integrate a sensory evaluation module comprising the measurement of intensities, through both measurements of change of electrical resistance and electrical conductivity, respectively. In many cases, the samples represented a limitation in the experimental design, where in several studies a control group was missing and the identification of physicochemical components of coffee was not contemplated, but rather an intensity of the statistically treated signals.

On the other hand, in the electronic eyes we observed that the color of roasted coffee is an indicator that largely determines the taste of coffee. The variables to be considered for such a statement must be standardized and controlled following the SCA protocols, both for green coffee and for roasting. The characteristics of the roaster must also be studied because the roasting curves are susceptible to variation in their flow and heat transfer caused by the material with which they were built, their ventilation systems, internal and external, and the type of heating element, gas or electrical resistance. As for the raw material, its grain size must be standardized, its density and humidity must be measured and thereby the initial roasting temperature must be defined, commonly in the range of 180-220 °C. The variety of coffee and the type of benefit that coffee has had (natural, honey, wash, etc.) also influences the obtaining of a homogeneous color in the bean. Medium shades of roasting are preferred, being related to the full development of Maillard reactions and some of caramelization, which are suitable for generating the expression of flavor such as sweetness, pleasant acid, and body in the final drink.

Regarding data fusion techniques, there was great variability in the studies presented by the authors, which provides an overview of the influence of the effects of coffee on the final treatment of the data. They observed some elements that represent good practices in experimental designs, such as the use of chemometric and statistical techniques, and the control of elements related to the raw material and the roasting process. However, these variable needs critical review and standardization for future research. The use of biomimetic (biologically inspired) statistical trends played a dominant role in most studies. New data analysis tools are also included. In addition, in some studies, records of other variables were acquired, especially in the near-infrared spectrum, which may support findings on color variables, and their relationship to time and temperature profiles in the roasting process. It is important to mention that the selected studies do not provide sufficient evidence on all the chemical reactions that develop in both the Maillard and caramelization stages, to directly relate the color of roasted coffee, as a non-enzymatic process, with the expression of flavor. In this sense, it is necessary to carry out new research that allows conclusions to be drawn on this subject, due to the complexity characteristics of the coffee roasting process, its heat transfer processes and the characteristics of the raw material. In this last aspect, it is necessary to consider the wide variability in the characteristics of the research. Therefore, there is little homogeneity between E-Eye, E-Nose and E-Tongue technologies and experimental design in descriptive studies. Variations in these characteristics make it difficult to reach a complete conclusion regarding the inclusion of these technologies in the quality assessment process. However, despite these variations, it was possible to observe some of the elements that were often present, especially the development of various data fusion strategies, combining the results of multiple instrumental sources, to improve the quality assessment and authentication of food. In this way, this review provides elements that can contribute to improving quality in future research on the evaluation of the quality of roasted coffee, using technologies that integrate different sources of sensory perception.

An exploration of instrumented systems for the analysis of food quality currently reports the use of fusion of data from the E-Nose and E-Tongue systems, and E-Eye in which it is intended that they not only identify and classify colors, smells and flavors, but that these attributes are quantified, offering a diagnostic tool as a complement to a quality evaluation process carried out by a panel of expert tasters, but supported by multivariate data analysis that can integrate the treatment and processing of visual, olfactory and taste data and signals, to represent a diagnosis of coffee quality in terms of the SCA protocol and generate decisions regarding the differences found in the process. This shows that there is a need to continue research related to the influence of the use of instrumental and data fusion techniques in the in-depth study of the variables that govern the development of coffee flavor expression. It is important to consider future research to observe and understand heat transfer processes and finite element analysis to consider the variables associated with the coffee bean in its roasting process, as a basis for monitoring the formation of more than 1000 volatile organic compounds VOC, which ultimately impact the aroma of coffee.

To complement this review, it is suggested to read the recent contributions of *"Recognition of the degree of coffee roasting using an artificial vision system"* (Leme et al., 2019)*"Modeling of structural deformations in a roasted coffee bean"* (Fadai et al., 2019) and "*Development and evaluation of roasting degree prediction model of coffee beans by machine learning"*(Okamura et al., 2021). This authors consider the system effective in the identification and approximation of the color of the coffee bean, which allows greater automation and reliability in the analysis of the degree of roasting and with the theoretical results of the modeling of the coffee bean, suggest directions for a possible improvement in the standard industrial coffee roasting techniques, which can allow the control of macroscale deformations of the cell matrix and thus improve properties such as taste, moisture loss and consistency of the final product, respectively.

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