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Review Article

A Systematic Mapping Study of Coffee Quality throughout the Production-to-Consumer Chain

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Coffee is one of the most consumed beverages in the world and is crucial in the economy of many developing countries. The search to improve coffee quality comes from many fronts, as do the many ways to measure quality and the factors that affect it. Several techniques are used to measure the different metrics to assess coffee quality, across different types of coffee samples and species, and throughout the entire process from farm to cup. In this work, we conducted a systematic mapping study of 1,470 articles to identify the aspects of quality that are the most important in the scientific literature to evaluate coffee throughout the processing chain. The study revealed that cup quality and biochemical composition are the most researched quality attributes. The main objective of the reviewed studies is the correlation between different quality measurements. The most used techniques are the analytical chemistry methods. The most studied species is *Coffea arabica*. The most used sample presentation is green coffee. The postharvest stage is the most researched, in which quality control receives more attention. In the preharvest stage, management practices stand out. Finally, the most used type of research was the evaluation research.

1. Introduction

Coffee is a highly popular beverage, it has been consumed for over 1000 years and today is consumed by about one-third of the world's population [1, 2]. It is the second most consumed beverage after water and the most widely traded tropical product [3, 4]. Global coffee consumption reached a record 168.1 million bags in coffee year 2018/19 [5] and is currently grown in about 80 countries on four continents [6]. By order of importance, the main producing countries are Brazil, Vietnam, Colombia, Indonesia, Honduras, and Guatemala [7], and as such, it plays a crucial role in the economies of several tropical countries as an important source of income, employment, and local development in the producing or processing regions. Moreover, smallholder coffee producers are responsible for 80% of global coffee production, which makes the activity extremely important in maintaining rural lifestyles, providing better incomes, and wealth distribution [8, 9].

Despite the background of global inflation, continued price fluctuations, and restrictions on trade, global coffee consumption continues to increase each year [5]. This rise in coffee consumption is related to its unique organoleptic attributes and the beneficial effects that have demonstrated its long-term intake [10] and, therefore, increases the demand for high-quality coffee and specialty coffees [11].

The criteria used to define the coffee quality differ throughout the different stages of the production-to-consumer chain are as follows. According to Leroy et al. [12], for the farmer, the quality of coffee depends on the easiness of the crop management and harvest, the production yield, and the price on the market. For the exporter or importer, coffee quality is related to bean quality, absence of defects, consistency of supply, the quantity at hand, physical characteristics, and price. For the roaster, it depends on the stability of characteristics, moisture and biochemical content, organoleptic features, origin, and price. At the consumer level, whose preferences differ depending on the country, the quality of coffee is associated with price, taste and flavor, health and alertness, origin, and environmental and sociological traits like fair trade and organic farming.

On the other hand, coffee science has a different approach to quality and the factors influenced by genotype (coffee size and shape, color, chemical composition, and flavor); environmental factors such as climate, altitude, water availability, soils; cultivation practices that encase farming and postharvest operations like fertilization, shade, crop management, coffee processing, and storage [13].

Traditionally, bean quality is assessed by their shape and size, color, the proportion of defective beans, and the taste of the beverage produced after the roasting of the beans. The flavor of the coffee cup is related to the chemical composition of the bean, which in turn is determined by the cultivar, the farming practices, and postharvest processing conditions such as fermentation, drying, and roasting [14]. On the other hand, the molecular science approach is to examine the molecular composition of coffee from each step of the process and establish how it is impacted and determine the effect that every molecule has on the final beverage [15]. Furthermore, the coffee must be a safe product with no risk to consumer health. The main issues of safety are contamination with pesticide residues and fungal mycotoxins, and international standards that prescribe permissible levels of these substances must be followed. Despite scientific advances that aim to standardize coffee quality descriptions, they are still questioned, debated, and negotiated [14].

Due to the economic impact of coffee around the world, research on coffee quality has become essential. Many studies have focused their efforts on understanding and improving it, and collectively they have shown that the variables that affect the coffee quality and the approaches to measuring it are quite diverse. While several surveys and literature reviews compile some of these studies, no literature systematically summarizes and categorizes these aspects, making a systematic mapping study necessary that provides an overview of this research topic.

Systematic mapping is a methodology frequently used in medical research and software engineering, but less in the exact sciences and, as far as we know, never in coffee quality research. This is arguably due to limited knowledge of the method. As Petersen et al. [16] indicated, a systematic mapping study provides a structure of the type of research reports and results that have been published in a research topic. This is conducted by categorizing them and presenting a visual brief of the results, i.e., the map. It often requires less effort while providing a more coarse-grained overview, identifying research gaps by graphing, and showing in which topic areas and for which research types there is a shortage of publications. Additionally, it gives indications of a lack of evaluation or validation research in certain areas. Therefore, systematic maps are primarily concerned with structuring a research area [17].

In this study, manual systematic mapping of 1,470 articles was performed with the goal of identifying the studies most relevant to the research area of coffee quality and investigating which quality attributes in coffee are the most popular in the scientific literature for assessing the different stages of the production-to-consumer chain.

Specifically, the contributions of this article are as follows:

(i) Identification of the quality measures used the most in coffee science
(ii) Identification of the principal objectives in the study of coffee
(iii) Identification of the methodologies that are the most common in coffee quality research
(iv) Identification of the species of coffee most investigated
(v) Identification of the most common type of coffee samples used in coffee quality research
(vi) Identification of the stages of the production-to-consumer chain most studied by researchers for coffee quality evaluation

2. Method

2.1. Systematic Mapping Planning. The mapping was conducted following the guidelines of Petersen et al. [16]: (i) definition of the research questions; (ii) search for relevant publications using appropriate databases like Scopus and the search strings defined by the research questions; (iii) screening of the articles to see which are relevant applying inclusion and exclusion criteria, (iv) keywording using the abstracts to obtain a classification scheme consisting of facets based on the research questions; (v) data extraction after the sorting of the abstracts into the classification scheme; lastly, the results are analyzed based on the research questions. The general process followed is summarized in the flowchart shown in Figure 1. It includes the number of publications found after the search, the number of total publications used for the systematic mapping (relevant articles), and the number of facets in the classification scheme.

2.1.1. Definition of Research Questions. The research questions are the most important part of any systematic study [18]. The research questions are the base for the entire methodology and cover the next aspects:

(i) The search process must identify primary studies that address the research questions.
(ii) The data extraction process must extract the data items needed to answer the questions.
(iii) The data analysis process must use the data in such a way that the questions can be answered.

The goal of this systematic study was focused on finding the studies on coffee quality and measures in relation to the production-to-consumer chain. The included research questions were related to the scope type of the samples, species of coffee, and, mainly, the coffee quality:

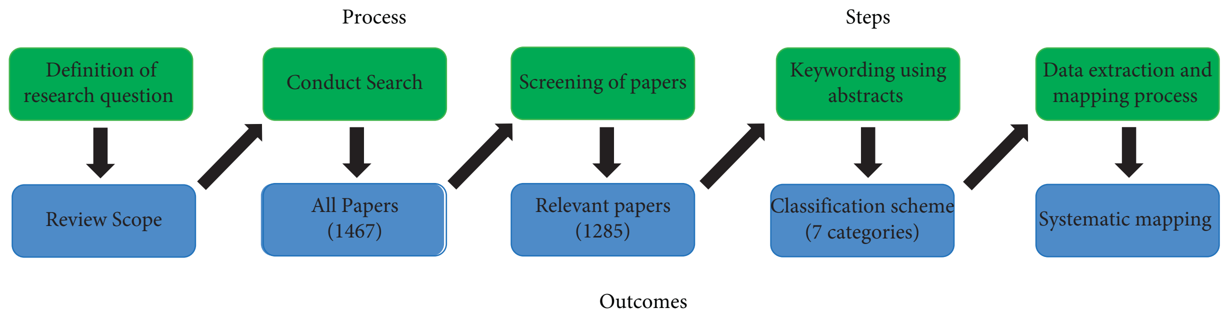

Figure 1: The systematic mapping process. Adapted from [16].

RQ1: What types of research articles have been published on coffee quality?

RQ2: What quality attributes have been considered for coffee using experimental data?

RQ3: What is the main objective of the research in terms of coffee quality?

RQ4: What kind of techniques have been used for measuring the coffee quality?

RQ5: What species of coffee are being investigated?

RQ6: What kind of samples are used in the measurement of quality?

RQ7: What stages of the coffee chain production are being investigated?

2.1.2. Definition of the Scope. The search is conducted by creating appropriate search strings and using them on scientific databases to identify the primary studies [16]. As was broadly mentioned before, the quality of coffee is a complex subject, and it is measured in multiple ways. Therefore, this was reflected by the multiple search strings applied in the process. The search strings were changing as the search was producing results as more keywords were added. First, from all the research questions, the groups of keywords are formulated, as shown in Table 1.

The search strings were structured using the PICO framework: Population, Intervention, Comparison, and Outcomes according to Kitchenham and Charters's method [18]. This method is applied to identify keywords and formulate search strings from the research questions. This method was used to better manage the keywords presented before.

Population refers to the scope of the study. Based on the study aim, the population is empirical research in coffee quality. Therefore, two basic keywords of "coffee" and "quality" were extracted from the population part.

Intervention refers to a methodology, tool, technology, or procedure that addresses a specific issue. In the context of this study, it includes terms like sensory evaluation and chromatography.

The comparison indicates the methodology/tool/technology/procedure in which the intervention is compared. In this study, different types of samples used in the intervention are compared, such as green coffee, roasted coffee, and arabica coffee.

Outcomes imply the factors of importance to practitioners, such as improved reliability, reduced production costs, and reduced time to market. In this case, the different objectives for measuring coffee quality were investigated by means of identifying the different strategies that have been used.

Keywords for the search string can be taken from each aspect of the PICO structure. The identified keywords were grouped into sets, and their synonyms were considered to formulate the search string.

Set 1: Scoping the search for coffee quality, i.e., "coffee quality".

Set 2: Search terms directly related to the intervention, e.g.,"sensory evaluation", "chromatography", "infrared".

Set 3: Search terms related to the comparison, e.g., "green coffee", "roasted coffee", "coffee arabica".

Set 4: Search terms related to the outcomes, e.g., "discrimination", "improvement", "correlation".

Set 5: Search terms related to the process of coffee, e.g., "drying" , "fermentation", "storage", "harvest".

2.1.3. Establishment of the Search Strategy. The Scopus scientific database was used in this study due to accessibility provided by the authors; in addition, Scopus is considered the largest and most complete scientific database for conducting literature reviews, relevance in science, and the most relevant electronic databases in food science [19]. This database supports nested Boolean operators and searching for titles, abstracts, and keywords. The search in the database was conducted between July 2020 and January 2021.

2.2. Search Execution. The resulting keywords from the PICO method were used in the Scopus databases, as mentioned before. These strings were formulated using a logical OR between synonyms and with a logical AND between the sets: for example, "cup quality" AND "infrared" OR "sensory evaluation" AND "roasted coffee" OR "green coffee" AND "discrimination" AND "fermentation". Due to the high number of keywords associated, the search strings are more complex, generating fewer results: for example, coffee quality AND (green coffee OR roasted coffee) AND (discrimination OR improvement) AND (infrared OR chromatography OR chlorogenic) AND (fermentation OR

Table 1: Keywords based on the research questions.

RQ	Keywords
2	Coffee, quality, coffee quality, cup quality, beverage quality, metabolites, flavor, bean quality
3	Correlation, discrimination, improve, measure, properties
4	Infrared, chromatography, PCR, RMN, sensory, chemical, antioxidant, mycotoxins, ochratoxin, pesticide, fungicide, yeast, caffeine, trigonelline, chlorogenic, sugars, lipids, metabolites, metals
5	Arabica, canephora, liberica
6	Roasted coffee, green coffee, brew, coffee cherries, espresso
7	Pre-harvest, post-harvest, rust, pest, harvest, post-harvest, dehulling, depulping, drying, fermentation, *hampei*, organic, storage, soil, washing, defects, origin, specialty coffee

drying OR harvest) produced three results, while coffee quality AND (green coffee OR roasted coffee) OR (discrimination OR improvement) AND (infrared OR chromatography OR chlorogenic) OR (fermentation OR drying OR harvest) produced 320 results. In this sense, shorter strings were used combining about two or three keyword sets, e.g., "coffee quality" AND ("mycotoxin" OR "ochratoxin") OR "Chromatography" AND ("green coffee" OR "roasted coffee"). Applying the different search strings in these databases resulted in 1,467 hits in total.

All the bibliographic data, i.e., full texts and abstracts, were exported and stored using the reference management system Mendeley by Elsevier for further analysis. Then, a sheet list with all the references was created for further classification purposes.

2.3. Selection of Primary Studies. It was necessary to define inclusion and exclusion criteria to extract the relevant articles from all the articles found during the search in the databases. These criteria were used to exclude studies that are not relevant to answer the research questions and therefore are influenced by them. As Petersen et al. [16] suggested, it was also found important to add the exclusion criteria of articles that only refer to "coffee quality" in the abstract introduction without addressing it any further or developing the idea. Following the inclusion and exclusion criteria, 182 articles were removed, remaining for the study 1,285 articles. Table 2 shows the inclusion and exclusion criteria considered for the systematic mapping review.

2.4. Data Extraction and Classification. The classification scheme is made based on keywords extracted from the abstracts to take the studies found into account. Following Petersen et al.'s [16] criteria, a pilot study was conducted on 200 articles in which keywording was performed. The abstracts of these articles were read while looking for keywords and concepts key to the contribution of each article. Then the keywords were combined in groups of concepts related to the research questions. Based on the pilot study, it was constructed the mapping classifications for extracting data. After several iterations, the data extraction produced the nine classification groups, as shown in Table 3.

As mentioned before, in this study, nine main groups or facets were created. Each facet was associated with a topic area, for example, quality metric, and was made up of the different categories derived from the keywording; in this case, cup quality, bean quality, biochemical composition, and soil quality comprised the rest of the categories. However, the research type facet reflects the research approach used in the articles; this facet is general and independent from a specific focus area, allowing the comparison with other systematic mapping studies [16].

The multiple category selections for each facet are stated in the last column. For instance, the value of the last column of RQ7 (research type) is single, and this shows that an article could only be classified by a single research type. In contrast, the value of the last column of RQ1 (quality metric) is multiple. This shows that one article could have as quality metric more than one alternative (for example, cup quality and bean quality).

From the classification scheme, all the abstracts were read, and the articles were classified into the nine resulting groups. When abstracts do not contain detailed information required to properly classify an article, the methodology section was read, and, where necessary, the full article was skimmed over. The facets used for the classification scheme in this study are explained in detail as follows.

2.4.1. Research Type. As Petersen et al. [16] proposed, it is taken into account that the general and topic-independent classifications allow comparing different systematic mapping studies from a similar perspective. The research type classification schema chosen for this work was the one proposed by [20] and summarized by Petersen et al. [16], which consists of six research types, and the research type called review articles was added to these six types.

2.4.2. Quality Metric. Coffee quality can be defined in several ways; the definition depends on the step of the process of the product. So, the articles were classified considering all the measurements that can define coffee quality, e.g., bean quality, cup quality, and biochemical composition.

2.4.3. Quality Objective. The articles were classified according to the objectives of the investigation in relation to coffee quality. This includes improving quality as in coffee breeding; discriminating quality as the origin or the species of coffee; correlating quality with different variables as different methods of fermentation; or measuring quality as in sensory analysis or physicochemical properties of the coffee bean.

Table 2: Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
(i) Studies published online before 01/02/2021 (ii) Studies evaluating and measuring coffee quality using at least one metric (iii) Papers with abstracts in English, Spanish, French, and Portuguese (iv) Papers from the databases Scopus (v) Books, articles, technical reports, and grey literature describing coffee quality studies	(i) The publication lies outside the coffee sciences domain (E.g., economics) (ii) Coffee quality is not part of the contribution of the article; the terms related are only mentioned in the general introductory sentences of the abstract (iii) The article presents no measurable outcome (iv) Literature that was only available in the form of abstracts and did not contain enough information to be considered for the classification scheme (v) Duplicates

Table 3: Classification scheme.

RQ	Facet	Categories	Multiple/single
1	Research type	Validation research, evaluation research, solution proposal, philosophical papers, opinion papers, experience papers, review papers	Single
2	Quality metric	Bean quality, cup quality, food safety, biochemical composition, soil quality, quality perception, crop yield, microbiological composition, physicochemical properties, crop quality	Multiple
3	Quality objective	Improve quality, measure quality, quality correlation, quality discrimination	Multiple
4	Technique	Sensory evaluation, physical evaluation, analytical chemistry methods, modeling, microbiological analysis, molecular biology methods, new technologies	Multiple
5	Coffee species	Coffea arabica, *Coffea canephora*, *Coffea liberica*, coffee, hybrids, blended coffee, not declared	Multiple
6	Coffee sample	Green coffee, roasted coffee, instant coffee, brewed coffee, cherry coffee, coffee plant	Multiple
7	Process' stage	Pre-harvest stage, post-harvest stage, brewing stage	Multiple
7	Pre-harvest stage	Soil conditions, coffee origin, environmental conditions, crop altitude, shade, genetic traits, coffee breeding, management practices, fruit development	Multiple
7	Post-harvest stage	Harvest, processing, Drying, sorting, pretreatment and additives, storage, packaging, roasting, grinding, brewing, quality control	Multiple

2.4.4. Technique. The articles were classified according to the kind of methodology used to research coffee quality. Articles with analytical methods that encase all processes requiring physicochemical measures; infrared and chromatography methods, for example, were encased in the instrumental chemistry classification; physical methods mainly include the evaluation of coffee beans quality; sensory evaluation for the measure of the attributes of the coffee beverage by tasters; modeling for articles that used multivariate methods or neural networks. Other classifications include studies that presented new technologies, microbiological analysis of coffee, and molecular biology methods to study coffee quality.

2.4.5. Coffee Species. The coffee tree is a perennial plant belonging to the Rubiaceae family. The *Coffea* genus consists of 124 species [21]. Still, commercially the most important are *Coffea arabica* (arabica coffee), *C. canephora* (robusta coffee), and *C. liberica* (Liberian or Liberica coffee, or excelsa coffee), which are used for beverage production, the two formers representing around 63% and 37% of the world production, respectively [22, 23]. The articles were classified by the species of coffee for which coffee quality was evaluated. This facet also includes hybrid varieties and coffee blends.

2.4.6. Coffee Sample. Studying the kind of samples used in the different studies of coffee quality and comparing how the results can vary is beneficial for decision-making for posing new studies, i.e., the measurement of caffeine content in green coffee and in roasted coffee. The kind of sample also varies with the type of quality measurement; i.e., the sensory evaluation is only achieved in brewed coffee. The articles were classified according to the type of sample used for the study of coffee quality: cherry coffee, green coffee, roasted coffee, instant coffee, brewed coffee, or coffee plant material.

2.4.7. Coffee Processing Stages. Musebe et al. [24] reported that coffee quality is determined by 40% in the field, 40% at postharvest primary processing and 20% at secondary processing and handling practices. That is, the tacit parameter, that is 40% of the quality, is due to preharvest factors and the remaining 60% by postharvest procedures. On the other hand, Folmer [15] affirmed that it is needed to view in a holistic way, like an orchestra where different players come together, and it is only by playing together that they can provide the highest quality. In addition, Louzada Pereira and Rizzo Moreira [25] defended that this relationship does not exist and that the two lines are blurred, proposing a relationship of equality or multiple correlations between various phenomena. In this study, to better understand the focus of the article, it was necessary to separate the different stages of coffee processing. Due to the significant number of possible classifications, the processing category was divided into preharvest and postharvest stages. The preharvest stage category includes all variables of the crop handling, and the postharvest stage starts at the harvest and continues with all the primary and secondary processing and handling practices. The articles were classified according to the steps of the coffee processing in the production-to-consumer chain involved in the study of coffee quality.

(1) Preharvest. The interaction of preharvesting variables shapes the overall quality attributes of coffee [26]. It is critical to coffee quality that the crop needs be met with the use of essential agricultural practices that influence production and productivity, as are phytotechnical practices, the use of improved cultivars, the control of pests and diseases, soil correction, fertilization, mineral nutrition, and irrigation [27]. These factors are mostly related to agricultural variables ranging from selecting a suitable geographical location to soil management and genetic material [13, 26]. The articles were classified according to all the steps of the preharvest stage.

(2) Postharvest. The postharvest practices are critical steps in determining the coffee beverage quality, making the beans suitable for transport and roasting. These methods involve the removal of the waste from the crop and taking off the outer layers of the beans [28]. These steps have an important part in guaranteeing the changes of the perishable coffee cherries into more stable green coffee beans, with a moisture content of 10–12% to avoid undesired fermentation [26]. Postharvest management activities are conducted to obtain suitably dried coffee beans for roasting and significantly contribute to the quality of the coffee beverage [29]. This process changes the chemical composition of green coffee beans that directly or indirectly influences the quality and end products [13, 30]. These activities involve a series of steps, including cherry harvesting, depulping, fermenting, drying, and storage. The number of activities also varies according to the type of processing method [29]. Following postharvest processing on farms, coffee beans can be transported to industrial plants, where semimanufactured or finished products are obtained for commercialization [28]. The articles were classified according to all the steps of the postharvest stage.

2.5. Validity Evaluation. To evaluate the validity of this mapping study, it was followed the suggestions by [17]. Next, it is discussed how the threats to the validity of this study were tackled.

Theoretical validity considers the quality of the sample of studies obtained from the population and potential researcher bias in the study selection and data extraction and classification.

Study identification: it is possible that two mapping studies with the same subject select different sets of articles [31]. To avoid that problem, it was used the PICO approach to systematically extract the keywords according to the objective of the research.

Data extraction and classification: the extraction of the data may introduce bias to the final results. To reduce this risk, it was performed over a fair number of articles reducing the risk of misclassified articles really affecting the final result. However, human judgment is generally prone to bias and cannot be completely eliminated.

Interpretive validity considers the validity of mapping study discussion and conclusions based on the results. This mapping study has solely relied on a quantitative analysis of the extracted data. The discussion and conclusions were drawn based uniquely on the quantitative results to reduce the problem of unclear conclusions.

Generalizability considers the degree to which the results can be generalized inside or outside the studied population. By utilizing a systematic way to construct the search string, identify articles, and obtain results, besides the fact that this work provides a good population sample, it is considered that the results of this study can be generalized to the population. However, since the study was designed for coffee quality using physical and chemical techniques, the results may not apply to other related populations, like health quality in general or medical research.

3. Results and Discussion

In this section, the results of the classification of the selected studies are presented. Thus, this section is structured in terms of the classification provided in Table 3, which also corresponds to the answers to the research questions shown in Section 2.1.1.

3.1. RQ1: What Types of Research Papers Have Been Published in This Area? The RQ1 classified the primary studies according to the research methods categories that Wieringa et al. [20] proposed, with an extra category added by the authors named review articles (see Figure 2).

The first category, with a 2.8%, is validation research and includes publications where the techniques investigated are novel and have not yet been implemented in practice. Techniques used are, for example, experiments, i.e., work done in the lab. For example, a new technique to measure pesticides in roasted coffee [32].

The majority of the primary studies (77.6%) are classified in the evaluation research category, consisting of articles that show techniques that are implemented in practice and an evaluation of the technique is conducted. That means it is shown how the technique is implemented in practice (solution implementation) and what are the consequences of the implementation in terms of benefits and drawbacks (implementation evaluation), for example, a spectroscopy technique to measure phenolic compounds in coffee and estimate sensory parameters [33].

The solution proposal classification, with 5.4%, contains publications where a solution for a problem is proposed; the solution can be either novel or a significant extension of an existing technique. The potential benefits and the applicability of the solution are shown by a small example or a good line of argumentation, for example, a new fermentation method to improve coffee quality evaluated by metabolomics [34].

The next category, philosophical articles, includes articles that sketch a new way of looking at existing things by structuring the field in the form of taxonomy or conceptual

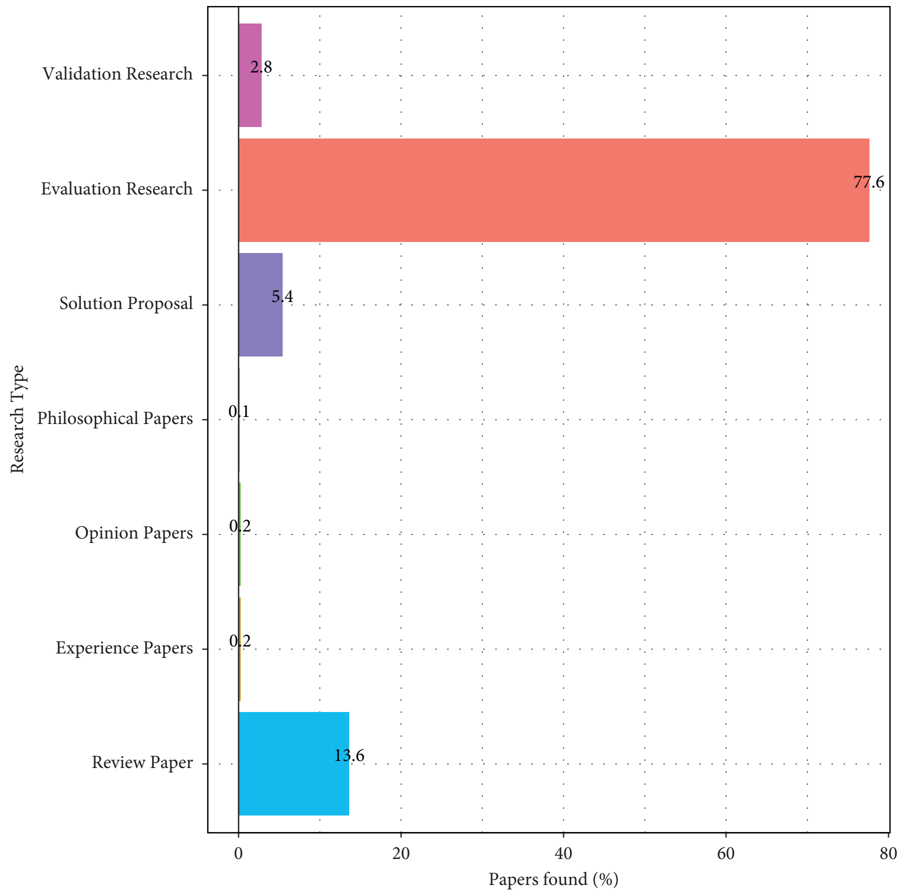

Figure 2: Percentage of the articles classified by research method.

framework. Of the primary articles, only one (0.1%) fills the requirements: Development of a "living" lexicon for descriptive sensory analysis of brewed coffee [35].

Only three articles (0.2%) were classified in the opinion articles category [15, 36, 37]. These articles express the personal opinion of somebody on whether a certain technique is good or bad or how things should be done.

The experience articles category also contains only three articles (0.2%) [38–40]. Experience articles explain what and how something has been done in practice, and it must be the personal experience of the author.

The last category is review articles, with 13.6% of the primary studies. This category encases all articles and book chapters that do not present original research but that summarize the existing literature or knowledge on a given topic and that generally provide a critical evaluation.

3.2. RQ2: What Quality Attributes Have Been Considered for Coffee Using Experimental Data? To answer the RQ2, the quality metric facet was created and contained ten categories (see Figure 3).

The bean quality category, with 20.6% of all the articles, includes several ways of measuring the quality of the coffee beans. For cherry coffees, quality is evaluated based on the maturity of the fruit. For green beans, it encases the physical quality of the coffee beans, aspects like size, density, and color. However, mainly, it refers to the presence of defects found in certain coffee batches, such as deviations in odor, color, size, and shape of beans and foreign bodies present in a relative amount of green coffee samples [14].

The cup quality category, with 39.3%, is a category that encases articles where the quality metric includes the attributes of coffee beverages that are distinguishable by senses and are usually assessed by professional coffee tasters. The results are expressed with a set of established terminologies like flavor, acidity, body, and cup cleanness[41].

The food safety category, with 27.3%, includes articles that show the study or measurements of contaminants in coffee, whether they originated from external sources like pesticides and mycotoxins or internal sources like acrylamide, that is produced during coffee roasting.

With most of the articles falling in this category, the biochemical composition category with a 53.3%, contains all articles that show research dedicated to the study or measurement of primary (sugars, lipids, etc.) and secondary metabolites (caffeine, chlorogenic acids, etc.) in coffee; also measurements of enzymatic and antioxidant activity.

The soil quality category, with 3.4%, consists of publications that study or measure soil conditions and/or physicochemical properties of coffee crops.

The category of quality perception, with 1.7%, includes the articles that center on studies of how external input

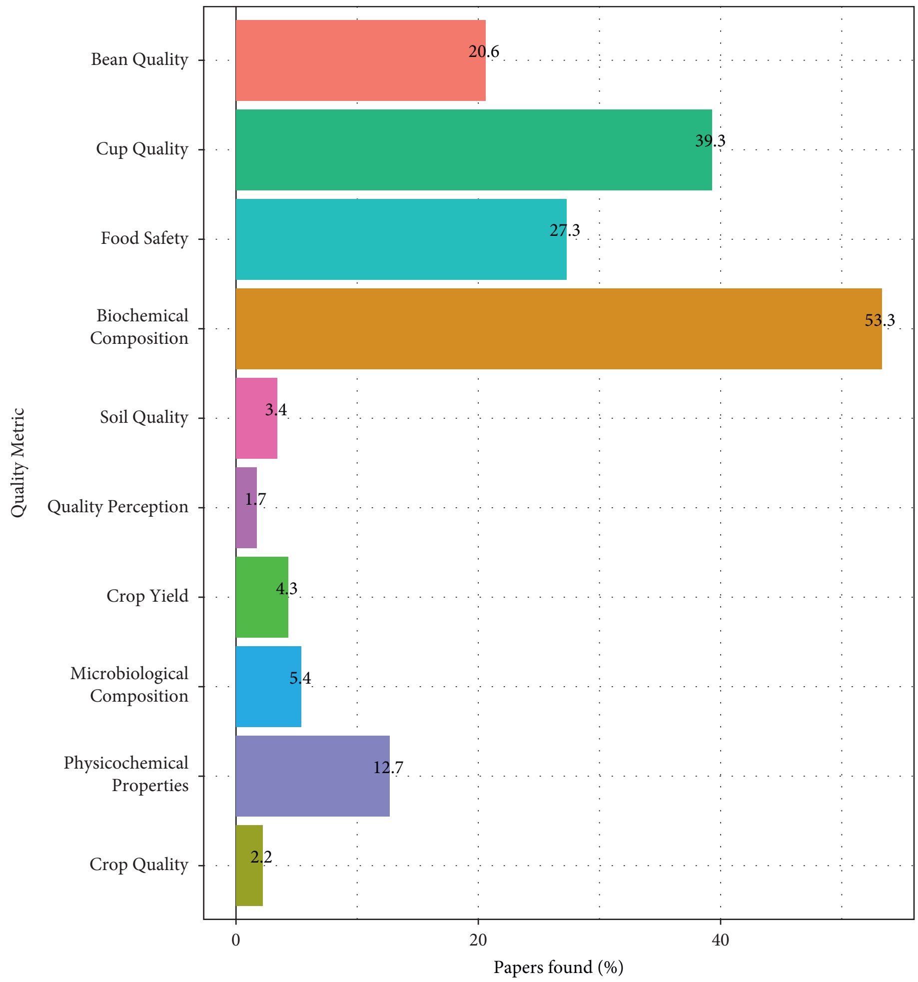

Figure 3: Percentage of the articles classified by coffee quality metric.

reflects on the cup quality perceived by consumers (design of the package, shape, and color of the cup).

The crop yield category includes 4.3% of the primary studies, including those that use the coffee crop yield as a measure of quality; the harvest of a coffee plant represents the actual yield.

The next category is the microbiological composition, with 5.4% of the publications that have microbiological measurements in any stage of the coffee process (yeast, fungus, and microbial communities).

With 12.7%, the physicochemical properties category is comprised of articles that include physicochemical measurements or characterization in any stage of the coffee process (pH, moisture content, and metals content).

Finally, around 2.2% of the crop quality category comprises publications that consider as a quality metric the health of the coffee tree (see Figure 4).

3.3. RQ3: What Is the Main Objective of the Research in terms of Coffee Quality? In total, 10.1% of the primary studies were classified in the improve quality category, including all articles that aim to enhance at least one measure of coffee quality, e.g., articles where the fermentation process variables are modified to improve coffee cup quality [42].

Moreover, 26.6% of the articles were classified in the measure quality category, in which the main objective of the research was to measure some quality metrics. This includes articles with the characterizations of new coffee varieties, cultivars, or genotypes [43] or articles with new or modified techniques for measuring quality, e.g., new techniques for measuring ochratoxin A levels [44].

Most articles were classified in the quality correlation category, with 798 articles and 62.1%. The principal objective of these articles is to study the behavior of the different variables that affect coffee quality during all the processes it goes through and the correlation between them, e.g., how the biochemical content of coffee; therefore, the coffee cup quality varies with the method of preparation of the coffee beverage [45] or with the coffee roasting technique [46]. This category also includes how the implementation of new techniques in coffee processing affects different coffee quality measures, e.g., how different drying techniques affect biochemical composition [47].

Finally, the quality discrimination category stands at 14.2%. This category encloses all the articles based on different kinds of data and variables, where coffee samples can be discriminated

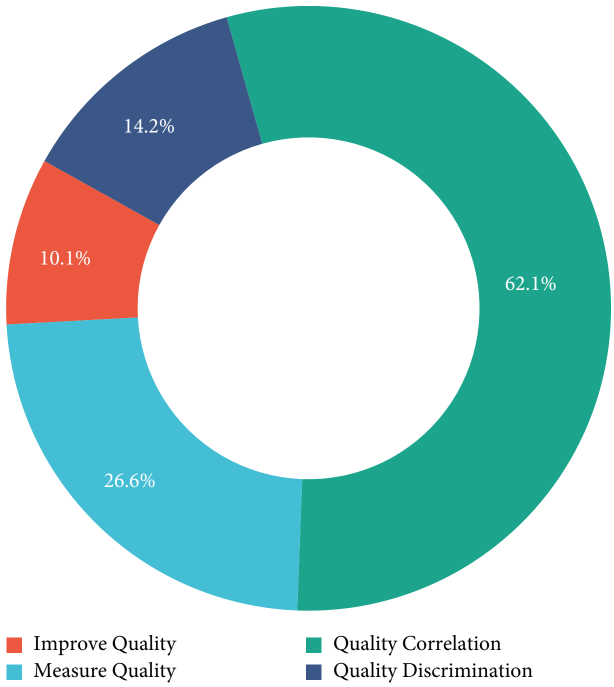

Figure 4: Percentage of the articles classified by coffee quality objective. The RQ3 led to the formation of the quality objective facet.

by some quality metric, origin, and type of coffee, e.g., discriminating traditional or specialty coffee based on data from their IR spectrums and chromatographic measures [48].

3.4. RQ4: What Kind of Techniques Have Been Used for Measuring the Quality? This facet, the result of the RQ4, classified all the publications according to the type of technique used to study coffee and its quality. Figure 5 shows the percentage of the articles classified by the technique of quality measure.

Thus, the sensory evaluation category comprises publications where the technique used to measure coffee quality was the cupping method, which amounted to 31.5% of the total publications, e.g., the evaluation of the sensory profile of the most cultivated *Coffea canephora* clones in the Western Amazon [49].

The category of physical evaluation incorporates 15.5% of the primary studies in which the quality of coffee is measured by the assessment of the coffee grain, including techniques like sorting by size, color, or defects, e.g., the effect of the shape and size of the bean on the cupping quality attributes of the beverage [50].

Of 1285 articles, 1007 (78.4%) are classified in the category of analytical chemistry methods indicating that in the investigation and measurement of coffee quality, instrumental chemistry techniques were used, such as chromatography and spectroscopy, and/or laboratory analysis like acid-base methods or potentiometry methods, for example, monitoring coffee quality during storage using the Raman spectroscopy technique [51].

The modeling category is the second most important category in the techniques for studying coffee quality, with 42.2% of the total articles. It includes the use of multivariate statistical methods, data mining, machine learning, and mathematical models in the data treatment juggling the many possible variables directly involved in coffee quality; for example, a computational model (based on users' tastes) recommends optimal coffee beans [52].

The microbiological analysis category includes 2.8% of the articles, involving those that present the use of techniques as microbial cultures, immunoassays, polymerase chain reactions (PCRs) for the identification, detection or enumeration of microorganisms in relation to coffee quality, e.g., the measurement of the microbiological characteristics of coffee inoculated with yeasts during the fermentation process [53].

The molecular biology methods category counts for 2.4% of the primary articles, which involve techniques to explore the molecular basis of biological activity in relation to coffee quality; how molecules control cells, their processes and characteristics, and activity and growth, e.g., the study of key galactomannan biosynthesis genes responsible for the accumulation of mannan storage polysaccharides on mature coffee seeds contributing to beverage quality [54].

The category of new technologies includes 6.1% of articles that present innovative tools and techniques, a new app or machine, to measure coffee quality, e.g., the development of a sensor for temperature measurement in a coffee machine [55].

3.5. RQ5: What Species of Coffee Are Being Investigated? In order to answer RQ5, all the articles were also classified by the coffee species the research was centered on. Figure 6 shows that 70.2% of articles study *Coffea arabica*. *Coffea canephora* and not-declared categories are closer together with 27.2% and 23.2%, respectively. The not-declared category mainly contains articles where the species of the research are irrelevant and therefore not mentioned, e.g., the development of a method to measure pesticide contaminants in coffee.

Few articles carried on studies in blended coffee (around 4.2%), that is, mixtures of varieties or species; coffee hybrids with 1.9% are genetically breeded coffee looking for a mix of characteristics, mainly from *Coffea arabica* and *Coffea canephora*.

Lastly, the coffee species *Coffea liberica* is the least studied with 1.1% of all the articles.

3.6. RQ6: What Kind of Samples Are Used in the Measurement of Quality? Answering what type of sample quality measurements are made on, six categories were produced (see Figure 7). Coffee quality can be measured in the coffee plant, in the coffee fruit or cherry coffee, in the coffee seeds after processing the fruit that is called green coffee, in the roasted coffee seeds or roasted coffee, on processed roasted coffee producing instant coffee, or lastly on the beverage itself or brewed coffee. The most popular way to measure coffee quality in the reviewed publications is over green coffee (46.2%), followed by brewed coffee and roasted coffee (40.0% and 37.9%, respectively). The cherry coffee category is

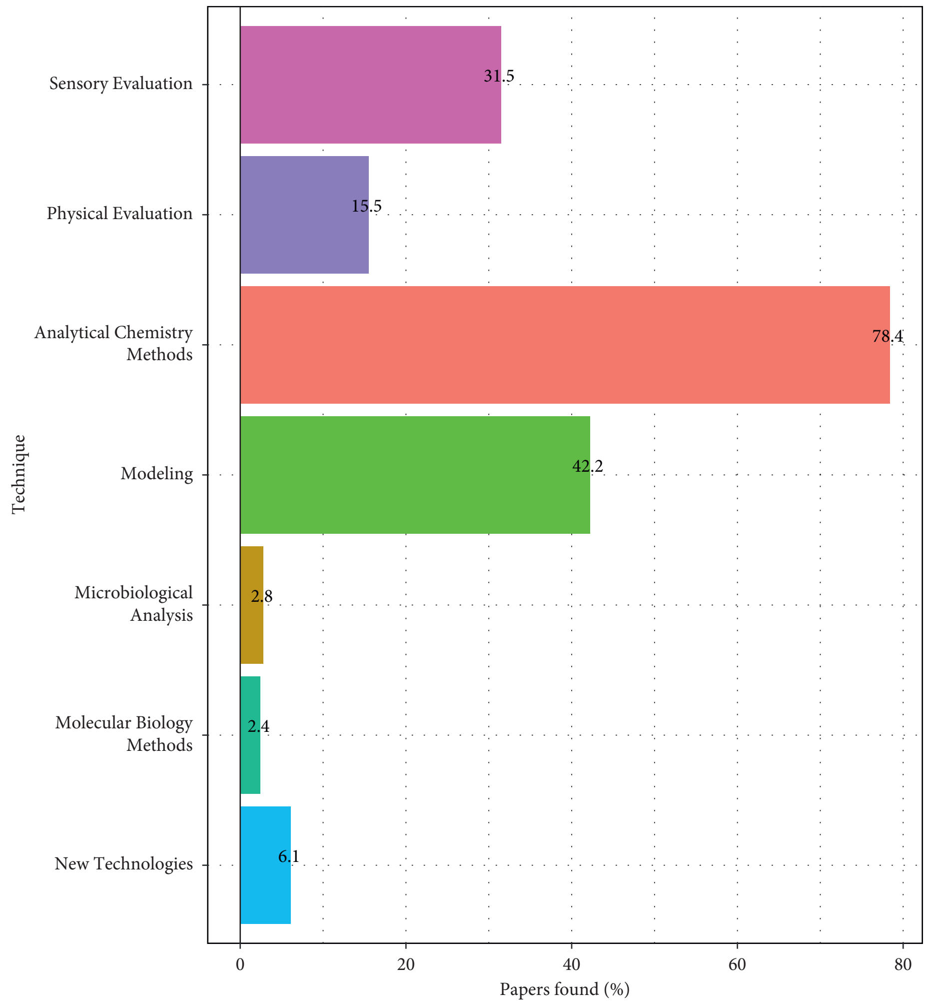

Figure 5: Percentage of the articles classified by the technique of quality measure.

studied in 18.8% of the articles, while instant coffee and coffee plant are studied in 6.6% and 6.5% of the articles, respectively.

3.7. RQ7: What Stages of the Coffee Chain Production Are Being Investigated? To answer this question, three facets were created. The first one is process' stage, which comprises the preharvest stage, postharvest stage, and brewing stage categories (see Figure 8). The first two categories, preharvest stage and postharvest stage, became the other two facets, so each publication was classified in the specific step of the complex process that carries coffee from the farm to the cup.

The first facet, process's stage, revealed that most of the publications are centered on researching the postharvest stage, with a 69.5% in this category, then preharvest stage with 34.9%, and the brewing stage with 12.4%.

The preharvest stage facet consists of nine categories that encompass the processes that are prior to the harvest (see Figure 9).

The first category, with 3.3%, is soil conditions and consists of articles that study the soil properties [56], physicochemical attributes [57], nutrition [58], fertility [59], microbiological conditions [60], and even soil color [61]and how it affects coffee quality.

The category origin (8.9%) includes publications that compare the origin of coffee with the respective quality [62].

The environmental conditions category with 4% consists of publications that study how the climate [63], the rainy and dry seasons [64], climate change [65], and factors like relative humidity, temperature, and water activity [66–68] can affect the coffee quality.

Crop altitude [69], terrain aspect [70], and slope [71] and how these affect the coffee quality correspond to 3.3% of articles.

The shade category includes publications that investigate types of trees [72] and the shade cover percentage of the coffee crop [73] with 2.7%.

Genetic traits (14.1%) is a category that includes all genetic characteristics of the coffee plant and fruits [74], the comparison of coffee species [75], and characterization of new varieties [76], genotypes [77], and cultivars [78].

The coffee breeding category (4.1%) consists of articles that study the development and resulting coffee quality of new varieties [79], cultivars [80], genotypes [77], or germ plasms [81].

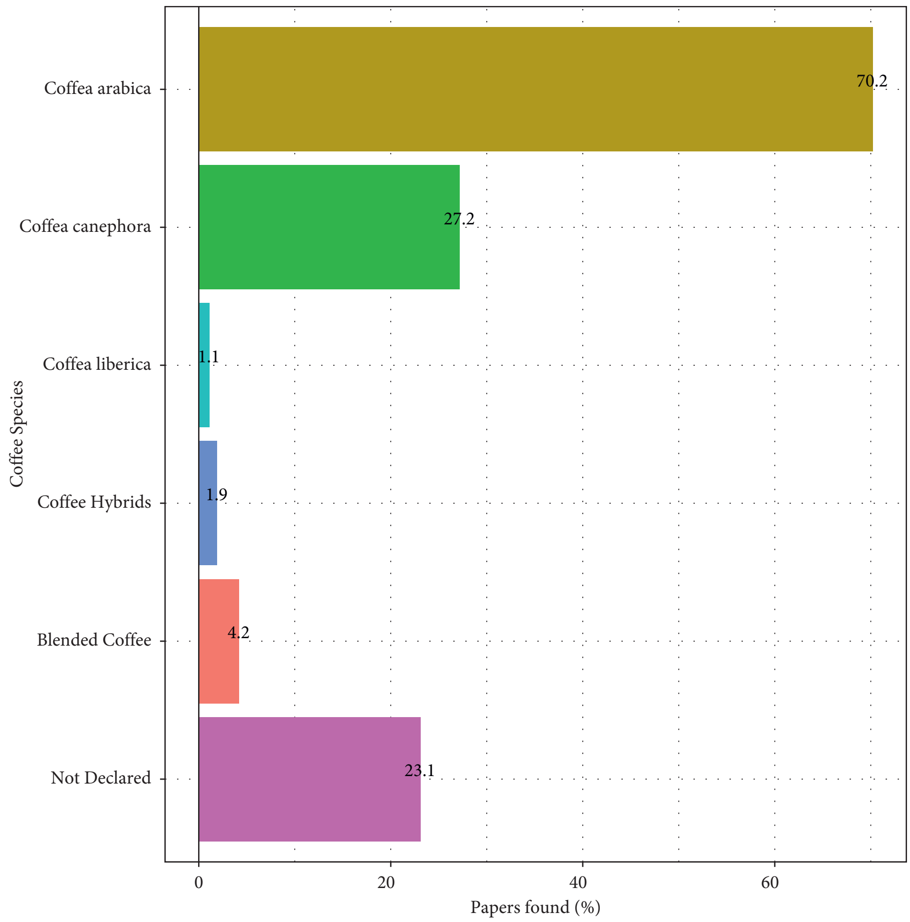

Figure 6: Percentage of the articles classified by the type of coffee species.

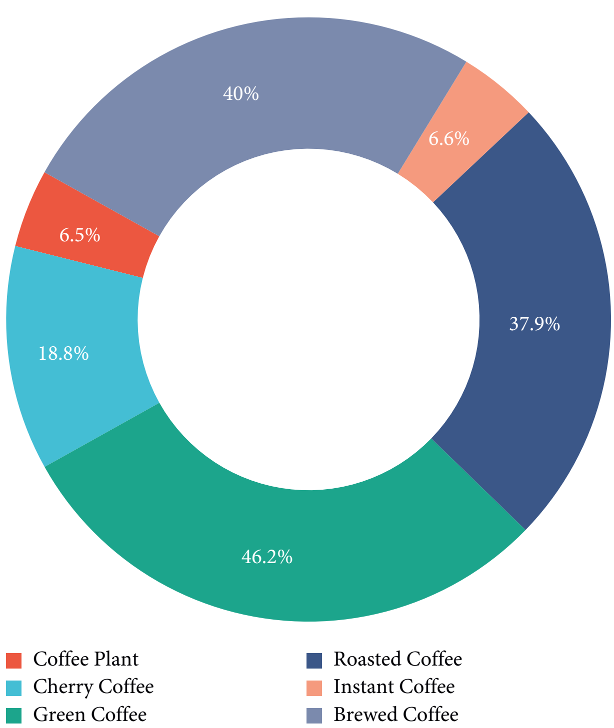

Figure 7: Percentage of the articles classified by type of samples used for quality measurements.

Management practices is the category that contains most of the articles in the preharvest facet with 28.6%. This category involves all publications that study the management of the coffee crop and includes practices like fertilization [82], plague management and control [83] as well as measurements of pesticides and mycotoxin contaminants [84], agroforestry practices [85], and specifically the practices around the production of specialty coffees [86], traditional coffees, and organic coffees [48].

Finally, the fruit development category (6.1%) contains all the articles interested in the coffee maturation stages [87], including flowering [88].

The postharvest stage facet also consists of nine categories around the processes that occur after the harvest, including the harvest itself (see Figure 10).

The first category corresponds to harvest (2.9%), which is related to coffee quality [89].

The processing category, the second in percentage with 19.1%, includes all publications that focus on all the different steps that lead the coffee fruit or cherry coffee to the dry seed or green coffee. There are two main methods used around the world: the wet method and the dry method. In the wet method, the cherry coffee is mechanically depulped to remove the skin, fermented to remove the mucilage, and then dried. It is mainly used for arabica coffees and coffees of higher quality [90]. In the dry method, the cherry coffee is

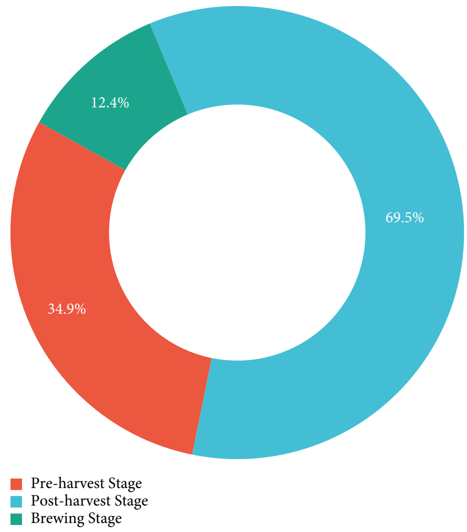

Figure 8: Percentage of the articles classified by the stage of the production chain.

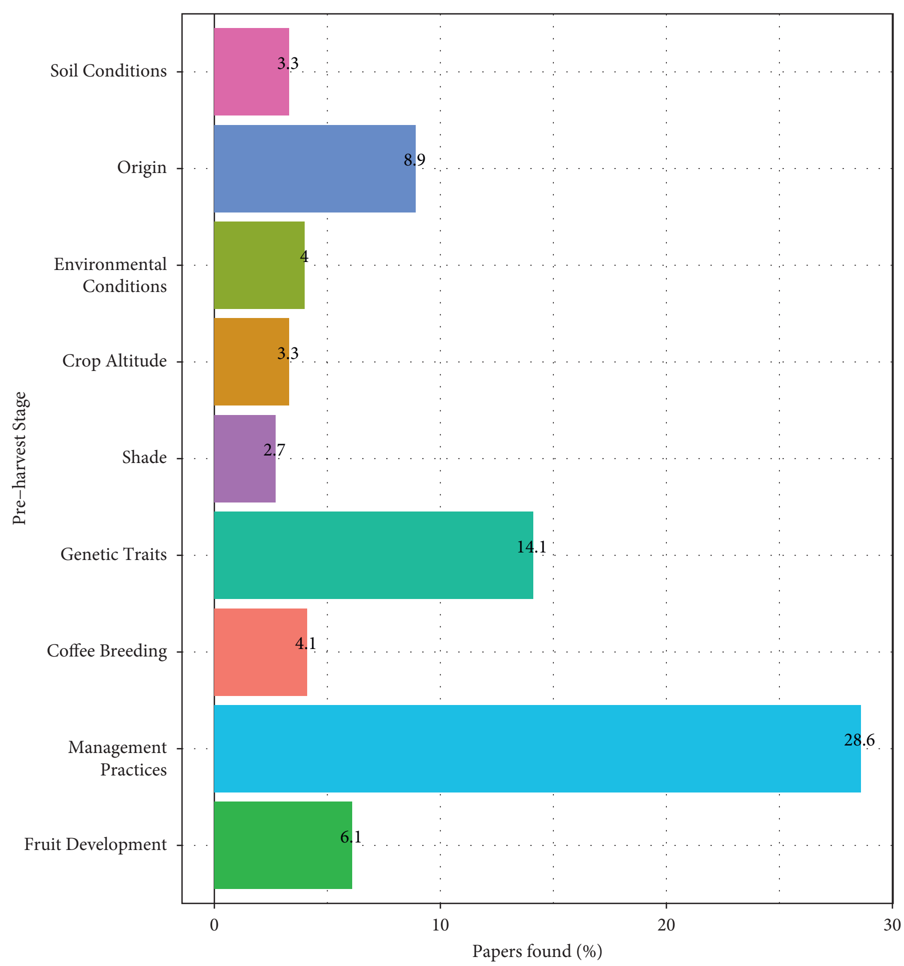

Figure 9: Percentage of the articles centered on the preharvest stage.

first dried and then mechanically dehusked. This process is used for most Brazilian, Ethiopian, and Haitian arabica coffees and for robusta coffee in most parts of the world [90]. This category includes articles centered on the processes of drying [91], fermenting [92], and wet [93] and dry processing [94] as a whole.

The sorting category (8.4%) focuses on articles that study coffee defects [95], the differentiation of defective grains

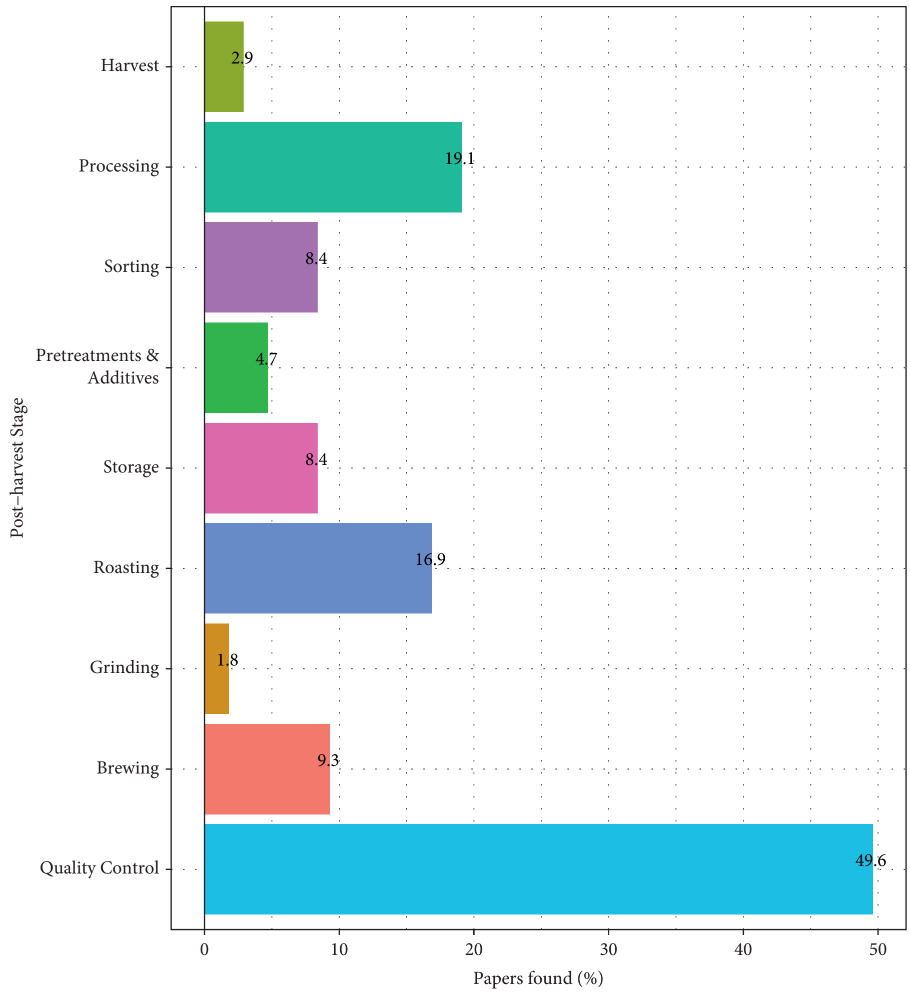

Figure 10: Percentage of the articles centered on the postharvest stage.

from nondefective [96], and grading, that is, the physical classification of green beans using different sized holes meshes [97].

The pretreatment and additives category (4.7%) includes processes over coffee to improve quality, like steaming the roasted coffee with defects [98], irradiation of green coffee to combat mycotoxins [99], and the use of enzymes in the drying process [100], or to prevent the acrylamide contaminant produced during roasting [101] and decaffeination process [102].

The storage category (8.2%) studies the different storage conditions and methods [103], the different packaging methods and materials [104], and how they affect coffee quality.

The roasting category (16.9%) involves all the articles that relate the roasting methods and technologies [46], roasting degree [105], speed [106], defects [107], and monitoring [108] and its effect on coffee composition [109] and quality.

The category grinding involves around 1.8% of the articles that study how the grinding grade [110] and particle size [111] affect the final quality and composition of roasted coffee.

The brewing category (9.3%) includes the different methods [112] of brewing coffee like espresso [113], cold brew [114], and Turkish coffee [115], and all the variables, including temperature [116] and pressure [117] that affect the final quality of the beverage.

Finally, quality control, the most populated category (49.6%), is transversal to all steps that occur after the harvest, from the cherry coffee to the brewed beverage. These publications include contaminant control [118], biochemical evaluation [119], sensory evaluation [120], and adulteration control [121].

4. Conclusions

In this article, we conducted a systematic mapping study on a body of literature that examines all aspects that affect coffee quality, in particular, the different measuring techniques, sample types, coffee species, and processing stages. First, the research questions were defined, from which a series of keyword strings were produced and then used in the Scopus database, resulting in 1470 studies. By applying inclusion and exclusion criteria, 1280 articles were selected for data extraction. As a result, it was found that the type of research articles published in the area is mainly of evaluation, where new techniques are implemented and evaluated. Furthermore, the most considered quality attributes using experimental data are biochemical composition, which involves the study and measurement of metabolites, followed by cup quality determined by cuppers. The main objective of the revised articles, in terms of coffee quality, is quality correlation, where different variables affecting coffee quality are contrasted. In addition, the most used techniques to measure quality were the analytical chemistry methods, in accordance with the main quality attributes measured, i.e., the biochemical composition. Likewise, the most investigated species of coffee is *Coffea arabica*, and the type of sample most used in the quality measurement is green coffee. Finally, among the three stages of the coffee production chain that are being investigated, the postharvest stage is the more studied. From the preharvest stage, the most investigated processes are the management practices that include fertilization and pest control. From the postharvest stage, the most researched process is quality control, which includes all the steps in every process dedicated to measuring the quality of coffee.

Data Availability

The data presented in this study are available on request from the authors.

Consent

Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

A.M.R.M. was responsible for the conceptualization; data processing and analysis; the writing, reviewing, and editing process. G.A.P.M. contributed to the review and editing process. D.C.C. was responsible for graphics, data processing, review, and editing. All authors have read and agreed to the published version of the manuscript.

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