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Perspective

Metrology, Agriculture and Food: Literature Quantitative Analysis

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Abstract: Great attention has been given in recent years to the relationships between metrology, agriculture, and food. This study aims at providing an analysis of the literature regarding the relationships between metrology, agriculture, and food. The Scopus online database has been used to extract bibliometric data throughout the search string: TITLE-ABS-KEY (Metrology* AND Agriculture* OR Food*), and the VOSviewer bibliometric software was used to visualize results as bubble maps. The novelty character of this perspective paper is to indicate and point out the main research themes/lines addressing the relationships between metrology, agriculture, and food by analyzing: (i) the authors of the published papers; (ii) the type of paper; (iii) the countries and institutions where the research is developed. Bibliometrics allows one to holistically examine entire scientific areas or sub-fields to get new qualitative and quantitative insights. These results represent a useful tool for identifying emerging research directions, collaboration networks, and suggestions for more in-depth literature searches.

Keywords: metrology; agriculture; food; biodiversity; literature quantitative analysis

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1. Introduction

Nowadays, an integrated, multidisciplinary, and interoperable approach can be seen as a modern way to research food and an innovative challenge to analyze and model agro-food systems following a holistic approach [1]. A great challenge is to identify a unique dimension of food-agricultural aspects in terms of quality and safety [2]. The recent work of Brown [3], remarks how metrology remains a unique important effort, and outlines the importance of updating the concept of metrology: it proposes a new feature—'measuring measurement'—, emphasizing the characteristic meta-thought associated with the discipline, which distinguishes it from any routine measurement.

Metrology is the science of measurements, that is the discipline that deals with defining the procedures for performing correct measurements. The International Bureau of Weight and Measures in 2004 defined metrology as "the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology" [4].

Nonetheless, metrology is not only meters, kilograms, and atomic clocks; the science of measurement wants to be closer to everyday life, for example taking into account the "farm to fork model", reaching the consumer, certifying the origin of food. Metrology has always supported the needs of the technological world, and today it is accompanying the spread of completely new technologies. The application of metrology to the environment and food is the last frontier in this research area.

Today, the agri-food sector represents a strategic asset for all countries in Europe and not only there, being one of the most important socio-economic activities, and it is crucial for providing employment, the supply of healthy and high-quality food, and facilitating the integration of small and medium-sized enterprises (SMEs), representing 99% of all businesses in the European Union in the food chain [5]. The focus of consumer needs is represented by food quality and authenticity, and in this direction food traceability and safety become critical factors in ensuring the quality and protection of food consumer interests. Furthermore, providing healthy and sustainable diets is a challenge of the agri-food sector [6].

Metrology is also a tool, throughout the use of advanced data analysis methods, at the service of the so-called "precision agriculture", which combines satellite and drone images with those of sensors and actuators in order to identify, for example, the most efficient interventions in relation to the real cultivation needs and the biochemical and physical characteristics of the soil. In fact, in recent years the need to enhance the resilience of communities and territories, the reduction of the consumption of natural resources and chemical and phytosanitary fertilizers, and the optimization of agricultural production has forced the development of innovative techniques for crop management. Thus, metrology may allow, thanks to the experience in the field of meteorological forecasts, the knowledge of historical and actual agronomic data, the coordination of the activities related to the reduction of emissions and the development of information technologies for precision agriculture, such as networks of sensors, geolocation systems and agrometeorological models.

In order to achieve climate-neutrality by 2050, while also considering pandemic situations such as the COVID-19 pandemic, the challenge is to promote economic recovery and return to facing global goals, e.g., clean growth and climate change, for example by means of innovative technologies as well as the management of big data within the perspective of sharing and dissemination at the e-cloud interface [7,8]. The novelty character of the proposed perspective work is to give a current snapshot on the relationships existing between metrology, agriculture, and food, and to indicate related current directions and collaboration networks by analyzing research themes and major contributors with reference to country/regions, institutions and types of published papers. In fact, the bibliometric analysis reveals the applications of metrology principles in the agricultural and food fields.

2. Materials and Methods

The overall landscape of the literature in the research field of metrology, agriculture and food relationships has been investigated through a bibliometric analysis. The literature quantitative research analysis consisted in the following main steps: (i) literature search based on Scopus online database; (ii) data extraction and analysis.

2.1. Literature Search

In July 2021, a search for metrology, agriculture, food relationship publications was carried out based on the Scopus database content. The Scopus online database (https://www.scopus.com/home.uri, accessed on 3 July 2021) was used to extract bibliometric data using the search string: TITLE-ABS-KEY ("Metrology*" AND "Agriculture*" OR "Food*"). Publications mentioning the relevant words or their derivatives in the title, abstract, or keywords were identified throughout the applied search strategy. The evaluated parameters were: trends of publications and citations, document type, authorship, country/region and institution.

2.2. Data Extraction and Analysis

Bibliographic data, e.g., publication year, publication count, citation count, document type, authorship, countries/regions and institutions, were assessed. For the basic analyses the functions of the Scopus web online platform named "Analyze" and as "Create Citation Report" were used. The "full records and cited references" were exported to VOSviewer

software (version 1.6.16, www.vosviewer.com, accessed on 3 July 2021) for additional processing procedures/operations.

The terms utilized in the title abstracts of publications and keywords of publications were analyzed by the above mentioned VOSviewer software (v.1.6.16, 2020) [9–11]: the paragraphs were broken down into words and phrases, and linked to the publications' citation data, in order to visualize the results as a bubble map. This approach has been previously used in different fields of study, including food, nutraceutical, and chemical areas [12–15]. In a term map, the bubble size indicates how frequently a term is mentioned in the articles. Two bubbles that are positioned more closely to each other reflect that the terms coappeared more often in the selected publications. The average citations per publication (CPP) are given by the color of a bubble.

Five was set as the minimum number of occurrences of a keyword. Out of the 3166 keywords, 108 met the selected threshold, and 3 of them were manually excluded.

3. Results

Three hundred and twelve publications were returned by the search: they covered the time range from 1970 to 2021 and were cited collectively 2183 times. The publication and citation trends for the relationships between metrology, agriculture and food research are reported in Figure 1. The first publication is the Proceedings of the Instrument Society of America (ISA) Silver Jubilee Conference and Exhibit on advances in instrumentation, located in Philadelphia on 26–29 October 1970 and also including subjects such as metrology, analysis instrumentation and food industry [16].

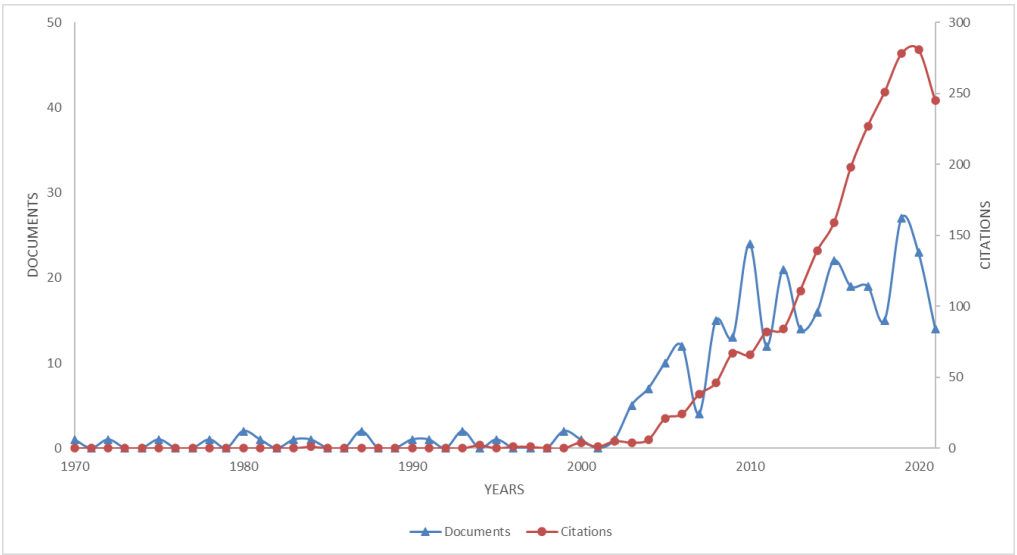

Figure 1. Publication and citation trends for the relationships between metrology, agriculture, and food research. (Bibliometric data were extracted from the Scopus online database).

The most recent "Review" is focused on the global situation of reference materials in assuring the quality and safety of the most consumed beverages in the world, i.e., coffee, cocoa, and tea, by discussing aspects related to reference material preparation processes, as well as the results of homogeneity and stability tests and their application, together with an overview of the patents developed for food. The authors remarked in the conclusion a clear need to develop certified reference materials and reference materials for these beverages for other analytes of interest, such as chlorogenic acids and other phenolic compounds [17]. The most recent "Article" showed the application of a smart pansharpening approach using kernel-based image filtering, as an example of numerous applications of remote sensing image fusion in monitoring, metrology, and agriculture [18]. Another application of innovative technologies is given by Fiorani et al. [19] on the use of a photoacoustic

laser system for food fraud detection as a reliable technique for the rapid screening of counterfeited ingredients in the supply chain, which needs further development.

Additionally, the most cited paper (300 times) is a paper by De Chiffre et al. [20] which reported industrial applications of computed tomography in different fields including the food industry.

The distribution of the types of documents relative to the 312 publications retrieved are shown in Figure 2. "Article" accounts for 50.3%, followed by "Conference paper" (26.3%), "Review" (8.0%), and "Conference Review" (6.4%). Among "Book", it is worth mentioning the one published in 2007 by Meinrath and Schneider [21] entitled "Quality assurance for chemistry and environmental science: metrology from pH measurement to nuclear waste disposal": the basic metrological concepts for measurements in chemistry and geochemistry like traceability, ISO uncertainties or cause-and-effect diagrams were discussed, and applications of metrological techniques in highly complex situations, i.e., in thermodynamics, geochemical modeling, hydrology and radioactive waste disposal, were given. Another book focuses on the description of voluntary standards, mandatory technical regulations, conformity assessment (testing and measurement of products), certification, quality and quality management systems as well as other management systems such as environmental, social responsibility and food safety management systems [22].

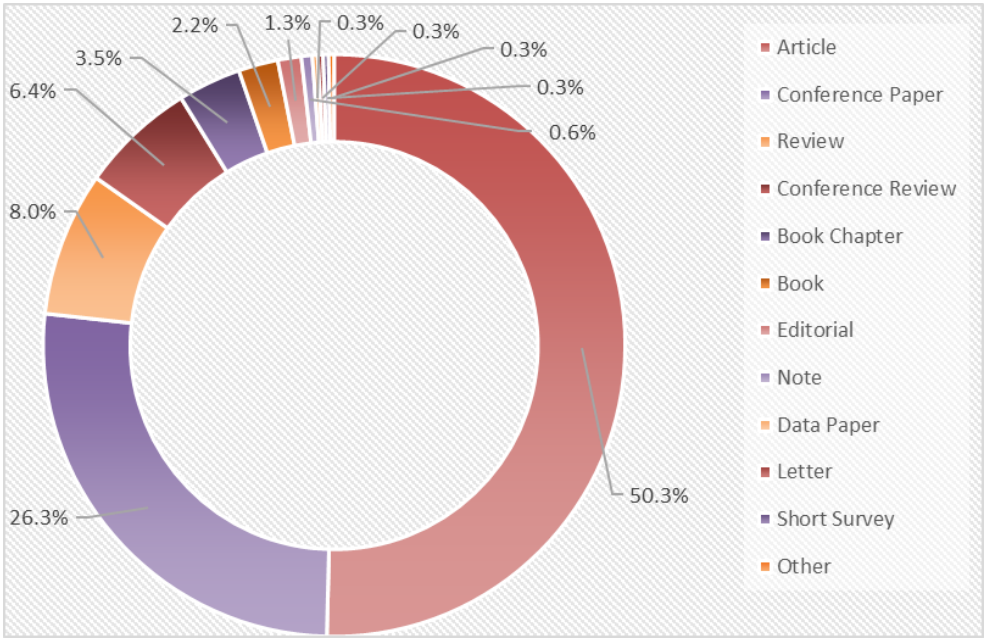

Figure 2. Distribution of the type of document. (Bibliometric data were extracted from the Scopus online database).

A book published in 2010 entitled: "Metrology in Industry: The Key for Quality" described an analysis of the metrological requirements needed to ensure quality, along with the organization of metrology, mastering the measurement process approach, the bank of measuring instruments, the traceability to national standards, measurements and uncertainties, the measuring environment, and others [23].

Among the "Editorial" category, the editorial published by Chirico and Bonavolontà [24] entitled: "Metrology for agriculture and forestry 2019" addressed recent advances in integrated monitoring and modelling technologies for agriculture and forestry.

Figure 3 reports the most productive authors. It should be noted that 'Anon' as Anonymous was originally ranked second by the Scopus 'Analyse Results' function, and it is not listed in Figure 3. Additionally, we underline that some of the most productive authors participate in the same collaborative papers.

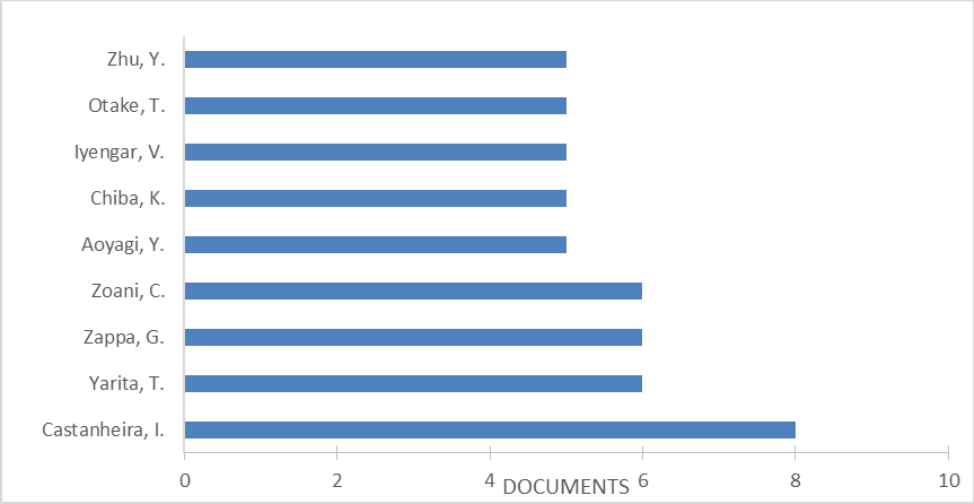

Figure 3. Most productive authors. (Bibliometric data were extracted from the Scopus online database).

Castanheira, I. (n = 8) resulted as the most productive author. The oldest work of this author regarding this matter pointed out the need to have reference materials in order to monitor the intake of nitrates [25]. Her most recent papers are represented by two conference proceedings presented at the 22nd World Congress of the International Measurement Confederation, IMEKO 2018, held from 3 to 6 September 2018 [26,27]; in one paper [26], the authors presented new Research Infrastructure METROFOOD-RI within the framework of the European Strategy Forum on Research Infrastructures (ESFRI) with the aim of promoting metrology in food and nutrition fields through the constitution of a well-organized and structured network of physical and electronic facilities: cross-cutting research activities and deliver advanced services were performed, covering several areas at the interface of different typologies of users: food business operators, research/academy, food control agencies, food policy makers, consumers/citizens. The core-services of METROFOOD-RI are the development and production of new (certified) Reference Materials (RMs). In the second one, published by Zoani et al. [27], feasibility studies for the development of new food matrix-Reference Materials (RMs) were presented. The feasibility studies included the following procedure Reference Materials preparation; procedures and guidelines definition for collecting characterization results and for processing the obtained data; Reference Materials characterization; homogeneity and stability studies; data processing and result evaluation, and three candidates for new Matrix-Reference Materials were tested: rice grains, rice flour, and lyophilized oyster tissue.

Castanheira' most highly cited paper (cited 11 times) focuses on ensuring food integrity by means of the integrated use of metrology and the application of FAIR (acronym for: findable, accessible, interoperable, and re-usable) data principles throughout the experience of the pan-European project METROFOOD-RI [28]. Among her papers, it is worth mentioning, also, the Conference Proceeding concerning the European Strategy on metrology in food composition databanks presented at the 20th IMEKO World Congress held from 9 to 14 September 2012 in Busan. In that document, the use of the International System of Units, modes of expressions and Reference Materials were indicated as being among the most important metrological tools for improving the quality of data in national Food Composition Databanks [29].

It is worth mentioning that METROFOOD-RI is composed of a Physical Infrastructure (P-RI) and an electronic infrastructure (e-RI). Among the relevant papers reported on the topic, like the ones by Zoani, C. and Zappa, G., it is worth mentioning the work of Alexandre [30], which describes the facilities which have been inventoried and classified in a database, providing an organized overview of the capacities of the distributed P-RI. These data were presented at the 3rd IMEKOFOODS Conference: "Metrology Promoting Harmonization and Standardization in Food and Nutrition", held in Thessaloniki from 1

to 4 October 2017. On the other hand, another work, presented at the same Conference by Presser et al. [31], and coauthored also by Zappa, G., described the development of a pilot e-RI where several datasets from different countries were used and interrelated to integrate national e-resources into a European-wide e-RI providing new functionalities. Additionally, a further position paper on METROFOOD-RI and its e-component were presented at the IEEE International Conference on Big Data, 2019, held in Los Angeles from 9 to 12 December 2019 [32].

The most cited paper of Iyengar, V. is a note focusing on metrological concepts for enhancing the reliability of food and nutritional measurements, including: high-quality reference standards, validated methods, robust sampling practices, proven calibration approaches, natural matrix reference materials, speciation chemistry, the assessment of measurement uncertainty and establishment of traceability links, certified reference materials to facilitate one aspect of traceability, and proficiency testing [33].

The most cited paper of Otake, T. is a research addressing the development of certified reference material—NMIJ CRM 7504—for the quantification of two pesticides in brown rice [34]. Another research from the same author was published in Food Chemistry in 2013 on the development of apple certified reference material for the quantification of organophosphorus and pyrethroid pesticides [35].

Figures 4 and 5 show the most productive countries/territories and institutions, respectively. The most productive country is represented by the United States with 48 documents. Among the documents reported for the United States, a book chapter was published on opportunities and limitations for metrology, represented by testing for foods derived from modern biotechnology [36]. An "Editorial" published by Iyengar in 2007 addressed differing perceptions of metrology in physics, chemistry, and biology [37]. Interesting results are also reported in a "Note" of Iyengar [33], previously described, and a "Note" by Koch et al. [38] on measurement science for food and drug monographs in the perspective of a global system. Among the "Article" category, the paper of Koch and Ma [39] on the approach of interfacing chemical metrology with pharmaceutical and compendial science adopted by United States Pharmacopeia indicates another relevant area of interest for the metrological approach.

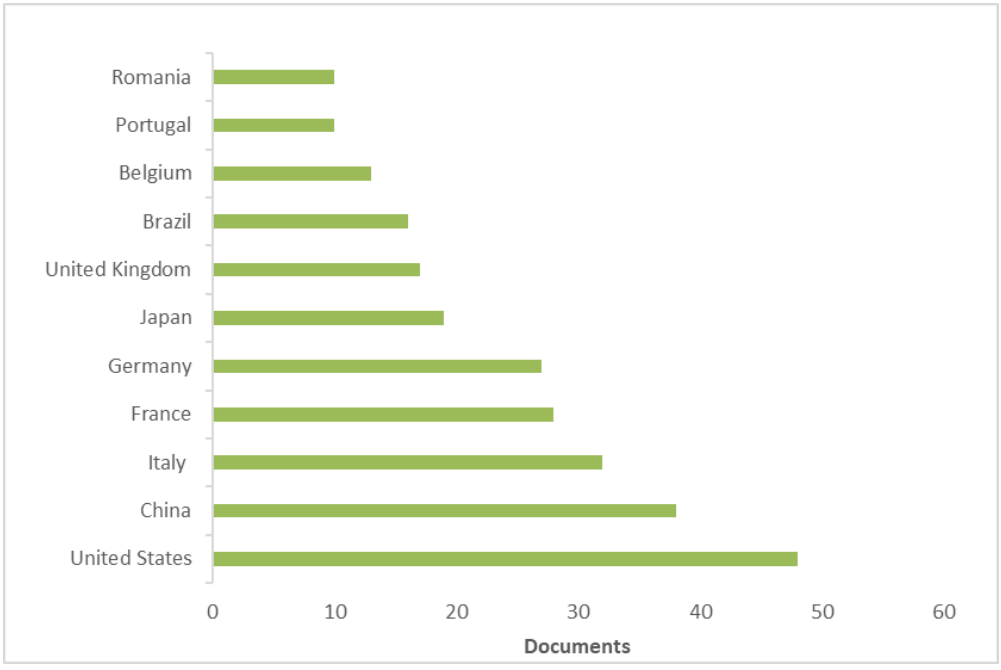

Figure 4. Most productive countries/territories. (Bibliometric data were extracted from the Scopus online database).

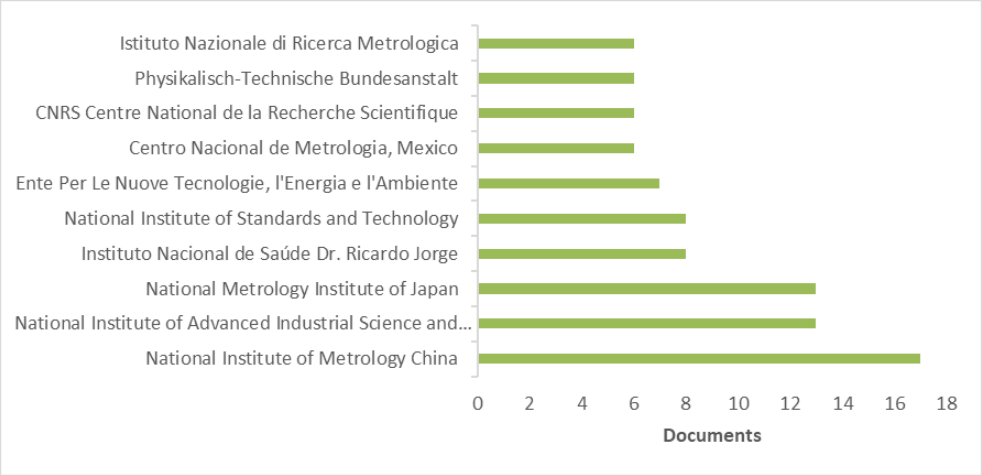

Figure 5. Most productive institutions. (Bibliometric data were extracted from the Scopus online database).

For China, the most cited "Article" (60 times) was addressed on the application of near-infrared spectroscopy to agriculture and food analysis; moreover, the authors marked the information sharing mode between the central database and end-user by using network technology and concentrating valuable resources [40]. One "Review" is reported and is focused on how a transfer program on metrology for safe food and feed in developing economies was started at the International Bureau of Weights and Measures to allow national metrology institutes or designated institutes to work together to strengthen their national mycotoxin metrology infrastructure, through a description of an application of an accurate characterization of a pure aflatoxin B1 material to avoid calibration errors. It is worth noting that mycotoxins, secondary metabolites produced from microfungi in some conditions, may represent a health threat for crops, food and feed and hence for humans through the carry-over process [41].

For Italy, among 32 documents, two reviews were relevant in the approach. One opens the door to the role of incurred materials in method development and validation in order to account for food processing effects in food allergen analysis [42]. The second is a stakeholders' guidance document for consumer analytical devices with a focus on gluten and food allergens [43]. In particular, the recommendations are based on the current known technologies, analytical expertise, and standardized AOAC INTERNATIONAL allergen community guidance and best practices for the analysis of food allergens and gluten [43].

The reported institutions have produced at least six documents. The most productive Institution is the National Institute of Metrology China with 17 documents. The most cited "Article" is a study describing an approach for the identification and determination of arsenic species in kelp extract [44]. Other important studies among the reported articles are the study of Guo et al. [45] on certified reference materials and metrological traceability for mycotoxin analysis and the study of Xue et al. [46] on reference material for the quantitative detection of *Escherichia coli*. The work of Sun et al. [47] on the comparison of maximum residue levels and the standard analytical method for pesticides in tea is another relevant example. It is also worth mentioning the recent work of Joseph et al. [48], a key comparison study on organic solvent calibration solution-gravimetric preparation and the value assignment of trans-zearalenone in acetonitrile.

For the National Institute of Advanced Industrial Science and Technology, the most cited paper is the paper of Zhu and Chiba [49] on the determination of cadmium in food samples by ID-ICP-MS with solid phase extraction for eliminating spectral interferences. Two reviews are also reported: one on a proficiency test in Japan for the elements in tea-leaf powder [50], the other on the assessment of technical problems in the analysis of inorganic elements in squid through proficiency testing [51].

One hundred and five terms in total were obtained from the literature quantitative analysis on publications, and they are visualized as a term map in Figure 6. Terms such as quality control, units of measurement, calibration, measurement/s, standard/s, reference standards, certified reference materials, and reference material appear as the top-recurring keywords: this shows the integrated research in the food and agriculture area, which is based on the control quality procedure and metrology principle (Table 1).

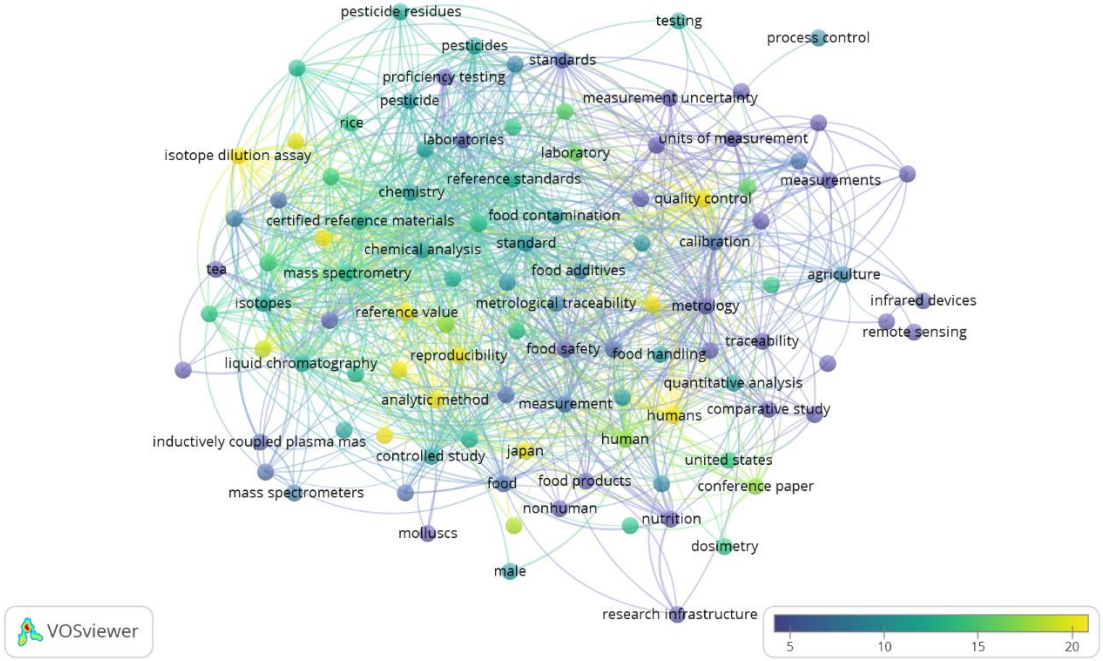

Figure 6. Term map for relationships between metrology, agriculture, and food research. The number of publications was represented by bubble size. The citations per publication (CPP) were given by bubble color. Two bubbles that are closer to each other reflect that the terms coappeared more frequently. (Bibliometric data were extracted from the Scopus online database and elaborated by VOSviewer software).

Table 1. The top-recurring terms on the relationships between metrology, agriculture and food research. (Bibliometric data were extracted from the Scopus online database and elaborated by VOSviewer software).

Term	Occurrence	Total Link Strenght
metrology	59	221
quality control	30	182
calibration	30	172
units of measurement	27	91
mass spectromentry	23	262
human	23	161
food safety	23	136
agriculture	22	69
measurement	21	167
standard	20	210
measurements	20	75
food analysis	19	176
reference standards	18	209
humans	18	139
chemical analysis	17	154
uncertainty analysis	17	90
chemistry	16	169
certified reference materials	16	167
reference material	16	67
standards	15	118

Analytical methods, reference materials, reference standards, calibration, and proficiency testing represent the key elements for quality control and ensuring the accuracy of

results, as indicators of metrology traceability. The traceability of routine analysis is critical for accurate measurements.

4. Conclusions

The proposed search methodology based on a quantitative literature analysis represents a useful and potent tool to identify emerging research directions, collaboration networks, research infrastructures, and authors that are more active in the selected area of research. This may provide suggestions for more in-depth literature searches. It can be concluded that the application of metrology could provide an important contribution to the overall frontier research in agriculture and food areas worldwide, aligning investigation, research, and innovation with society's values, needs, and expectations. The proposed perspective could represent a starting point for indicating the importance of metrology in the explored areas of research, which also impact health, traceability, sustainable economy, and safety in the agro-food system, among other things.

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