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REVIEW ARTICLE

Analysis of the scientific knowledge structure on automation in the wine industry: a bibliometric and systematic review

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Abstract
The objective of this research is to analyze the knowledge structure of the academic literature indexed in the Core Collection of the Web of Science on automation in the wine industry, from the first registered article in 1996 to 2022, in order to identify the latest trends in the study of this subject. A bibliometric and systematic analysis of the literature was carried out. First, for the quantitative analysis of the scientific production, the bibliometric study was conducted, using the WoS database for data collection and the VosViewer and Bibliometrix applications to create the network maps. Second, once the literature had been examined quantitatively, content analysis was undertaken using the PRISMA methodology. The results show, among other aspects, the uneven distribution of the examined scientific production from 1996 to 2022, that computer vision, data aggregation, life cycle assessment, precision viticulture, extreme learning machine and collaborative platforms are the major current keywords and the predominance of Spain and Italy in terms of scientific production in the field. There are various justifications which support the originality of this study. First, it contributes to the understanding of academic literature and the identification of the most recent trends in the study of automation in the wine industry. Second, to the best of our knowledge, no prior bibliometric studies have considered this topic. Third, this research evaluates the literature from the first record to the year 2022, thereby providing a comprehensive analysis of the scientific production.

Keywords Knowledge structure · Automation · Wine industry · Bibliometric review · Systematic review

Introduction

Automation in the wine industry has led to a revolution in reducing costs and improving quality [18], allowing producers to focus on innovation and flavor improvement [68], as well as enhancing detailed production record keeping [1], which is essential for early detection of problems and ensuring consumer satisfaction.

Automation can be integrated throughout the entire value chain of the wine industry, starting with the implementation of advanced machinery in grape harvesting, which facilitates winemakers to accelerate this essential process [7], continuing with grape pressing, optimizing the extraction of juice from the skins in an efficient manner [65] and ending with the bottling, labeling and transportation phase, allowing producers to increase their production capacity in reduced timeframes [4] and ensuring faster and more accurate execution [58].

Nonetheless, the adoption of automation in the wine sector is not without challenges; first, the wine industry is characterized by its deep roots in traditions and processes that have remained unchanged for years, making the automation of these a task of considerable complexity [61]; second, the acquisition of automated equipment represents a significant investment, forcing wineries to carefully evaluate the profitability of such investment and the compatibility of new technology with existing processes [54],third, a technical skills gap may exist in the workforce, as winery employees lack experience with advanced technologies, which can complicate the effective implementation of automated solutions [68] and, fourth, although automation promises quality improvements, it is imperative that automated systems be meticulously designed and evaluated to ensure compliance with established quality and safety standards [21].

The main objective of this study is to examine the structure of knowledge associated with automation in the wine industry since, to the best of the authors' knowledge, there

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are no previous literature reviews that have addressed this topic, making it possible to discover for the first time the key characteristics of this scientific production, such as the leading institutions, prolific authors and countries where production is concentrated, as well as to examine the main topics that currently occupy researchers in this field. To achieve this end, a bibliometric analysis is initially conducted, proceeding with the quantitative examination of the scientific production, and, subsequently, a systematic analysis is carried out to review in-depth the 39 records identified from 1996 to 2022, thus allowing to pinpoint the research fronts on the subject and, based on them, to propose future research lines. In fact, such a mixed methodological approach, based on bibliometric (quantitative approach) and systematic (qualitative approach) review, is carefully designed to provide a comprehensive view on contemporary research in the specified area, serving as a navigational tool through the complex landscape of prevailing trends, leading scholars and organizations, major publications in the domain, research fronts, and the future trajectory of publications.

Thus, the study aims to answer the following three Research Questions (RQ): (RQ1) What are the current trends and future prospects for automation in the wine industry? (RQ2) How is the scientific knowledge around this topic structured? (RQ3) What are the implications of these trends for academics, practitioners and policy makers in the wine industry? By addressing these RQs, the investigation aims to improve the understanding of automation in the wine industry, with the study being valuable for both wine academics and wine industry practitioners.

In order to achieve the objective set, the introductory section is followed by Materials and methods, which details the methodology employed, Results and discussion presents the findings of the study, and finally, Conclusions and future research agenda shows the main conclusions derived from the study, the research agenda, as well as the limitations and future research lines.

Materials and methods

This study conducted a bibliometric analysis using the Web of Science (WoS) database. Boolean and proximity operators, along with markers, were utilized to evaluate the quality and accuracy of the selected works. It should be noted that the WoS Core Collection was chosen for its rigorous inclusion criteria for articles.

The three indexes selected from the WoS Core Collection were the Science Citation Index Expanded (SCI-E), Social Sciences Citation Index (SSCI), and Emerging Sources Citation Index (ESCI). SCI-E is an extensive index of citations from scientific and technological journals since 1900, including 8,000 scientific journals and 12,000 conference and press journals [15]. SSCI includes references from approximately 3000 social science journals, featuring both press and conference journals [13]. ESCI is an index of citations which encompasses emerging science journals as well as some press and conference journals, in an effort to represent the variety of scientific publications, such as those from developing countries, and includes more than 5000 journals [14].

After evaluating the value of the WoS Core Collection, a search was implemented to identify articles related to the topic. Multiple efforts were made to evaluate the most relevant results and the least pertinent ones in order to eliminate any extraneous discoveries. Ultimately, it was determined that the most appropriate search equation among the available options was the following:

$$\text{TS} = ((\text{automation})\ \text{AND}\ (\text{wine} *))$$

The search equation was divided into two categories: automation and the wine industry. The AND operator was utilized to limit the results to papers that provided insights from both groups, while the wildcard (*) was used to include different word forms in the accessible results. It is important to note that only the AND operator was used because we wanted to prioritize the optician of results linked only and exclusively to the pre-established research objective. Likewise, the wildcard symbol was not applied to the automation category to avoid obtaining results that were not directly and explicitly linked to automation. Boolean operators are a major element of bibliometric reviews as they enable users to formulate intricate and specific queries to gain more relevant information. They can also be employed to narrow or extend the search to particular topics, documents of certain years or types, allowing researchers to get the most meaningful results while reducing searching time. These parameters were applied to the title, abstract, and keywords of the papers, and the documents added by WOS until 2022.

On October 5, 2023, the application of a search algorithm resulted in the acceptance of 39 articles. In order to analyze the scientific output, the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA statement) was utilized due to its potential to enhance the reliability and reproducibility of reviews, its comprehensive nature, and its widespread application in bibliometric studies [43]. The PRISMA methodology is beneficial for augmenting the transparency and communication between authors and readers, thus verifying that the results are dependable and reproducible [41]. This is recommended for the purpose of improving the quality of research studies and allowing readers to comprehend the results more easily, which reduces the chances of bias and mistakes in data collection [72]. After accepting only scientific production in the form of articles and eliminating research that did not aim to analyze automation in the wine industry, the number of documents was reduced from 108 to 39, thus forming the corpus of articles to be examined (see Fig. 1). In particular, after the selection of articles only, the number of records was reduced from 108 to 77 and, subsequently, articles were checked record by record to ensure that they explicitly addressed automation in the wine industry, eliminating 38 records that did not address automation in the wine industry, thus resulting in a sample of 39 articles.

The analysis of the scientific production was conducted by selecting multiple classification variables. Initially, the records were separated according to the year of publication in various journals to determine the level of interest in the topic over time. Subsequently, the main journals for disseminating research results were specified. In addition, a network and overlay map was generated through VosViewer to find out the main keywords used in the studies analysed, as well as their study over time. Authors were identified and the institutions to which the authors belonged were studied. This analysis was completed with the study of the network of collaborations, as well as the analysis of scientific production by country, both of which were carried out using the Bibliometrix software. Finally, once the scientific production had been quantitatively examined using the VosViewer and Bibliometrix applications, the content of the articles examined was reviewed following the PRISMA guidelines.

Results and discussion

The present study analyzed a collection of articles on automation in the wine industry. The findings shown in Table 1 account for the relevant data of the papers, such as the number of sources and papers and the average age of the articles, as well as the number of citations received and references used. The keywords and authors of each paper are also included.

Table 1 General information on the scientific production analyzed

Main information data	
Sources	29
Documents	35
Document Average Age	11.4
Average citations per doc	19.08
References	980
Document contents	
Author's Keywords (DE)	140
Authorship	
Authors	154
Authors of single-authored docs	0
Authors collaboration	
Co-Authors per doc	4.34
International co-authorships %	28.95

Source: own elaboration

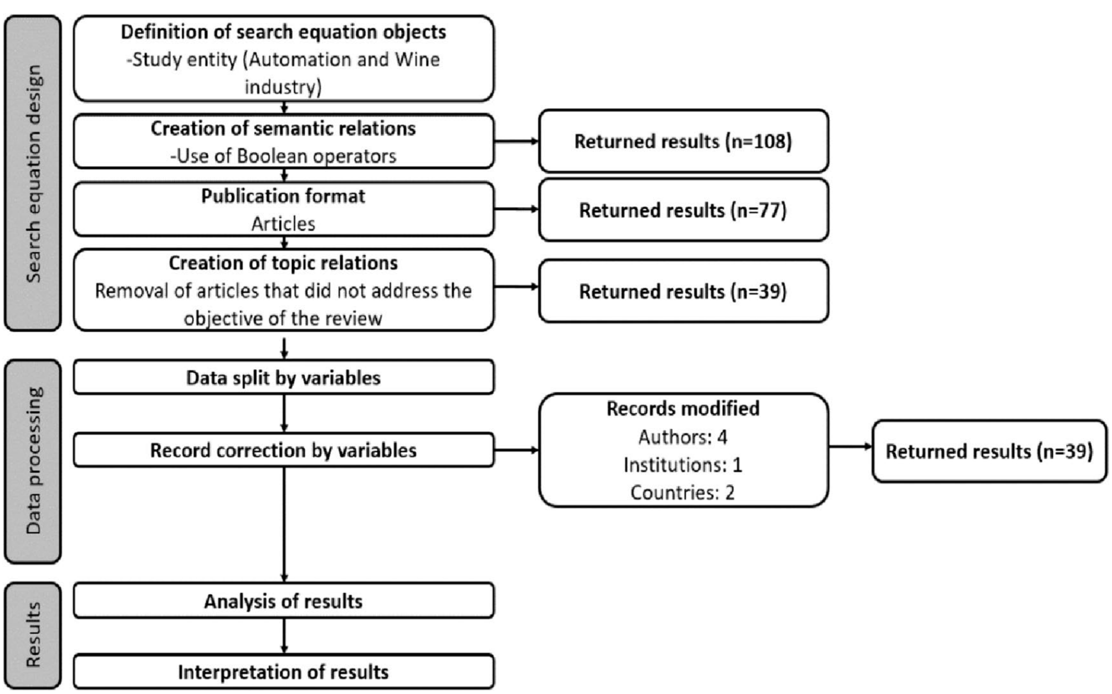
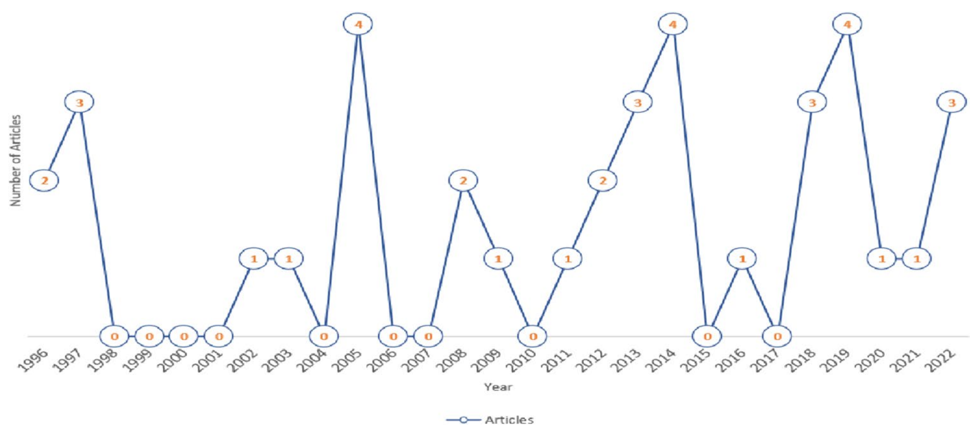


Fig. 1 Flow diagram about the bibliometric review procedure developed. Source: own elaboration based on PRISMA guidelines

As for the temporal evolution of the scientific production, Fig. 2 shows how it is distributed irregularly from 1996, the year in which the first academic articles on the subject were published, to 2022. Specifically, the distribution of scientific production follows the shape of sawtooths, experiencing three notable peaks with 4 publications relating to the years 2005, 2014 and 2019. However, despite the discontinuous evolution, it is necessary to highlight the efforts to address the subject throughout the period analyzed. This academic effort on the subject may be due to several factors. On the one hand, the study of automation solutions in this sector allows greater efficiency and productivity in an increasingly competitive industry, enabling greater precision in manufacturing processes, resulting in higher quality wines [44]. Automation can help reduce labor costs and save time, resulting in higher profits for producers, and can also help improve quality control and food safety, which are of great importance to the industry [22]. On the other hand, the growth of scientific production in the WoS Core Collection in the last decade, derived from the increased indexing of journals in this collection [60], may result in an increasing number of computable articles.

Figure 3 shows the main avenues for disseminating research results related to automation in the wine industry. The first journal is Analytica Chimica Acta (4), from the Elsevier publishing house, followed by Journal of Agricultural Engineering (3), Journal of Chromatography A (3), Journal of AOAC International (2), Water Science and Technology (2), Agriculture and Human Values, (1), Analytical Chemistry (1), Chemical Papers (1), Computers and Electronics in Agriculture (1) and Data (1). It should also be noted that the top three publishers in terms of scientific

Fig. 2 Evolution over time of the scientific production analyzed. Source: own elaboration based on Bibliometrix®



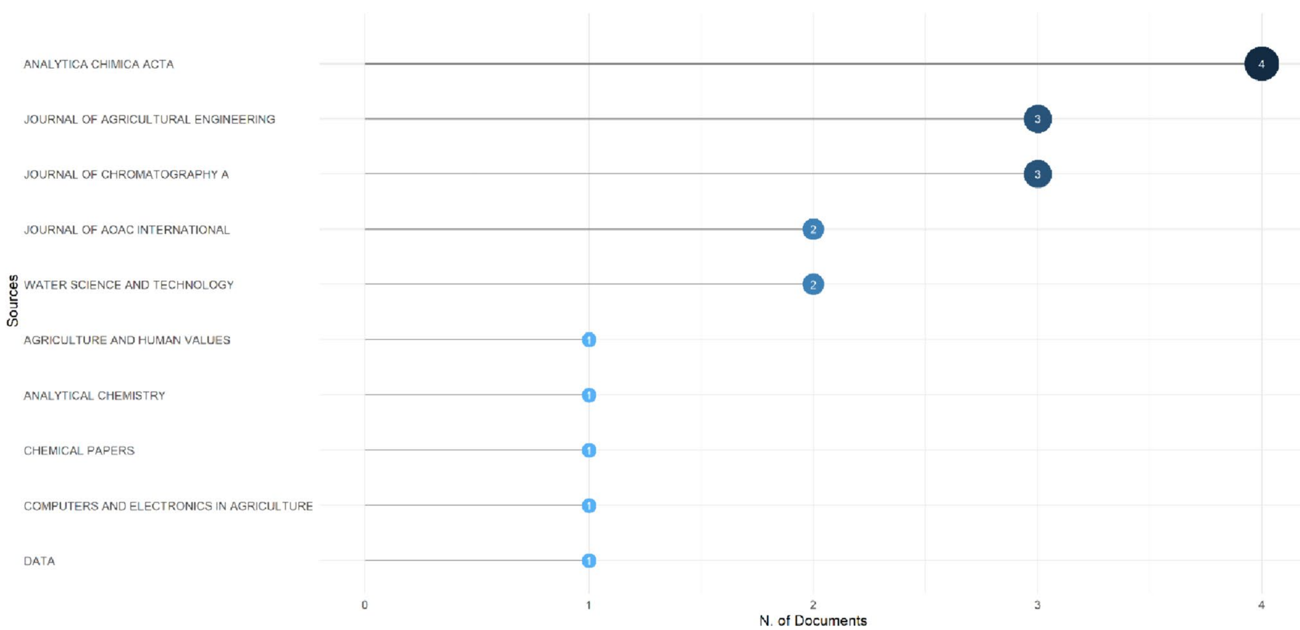


Fig. 3 List of the top ten most prolific journals in the field of automation in the wine industry. Source: own elaboration based on Bibliometrix®

production indexed in one of their associated journals are Elsevier (14), Springer (4) and Wiley (3).

To determine the topics analyzed in the scientific production under study, an analysis of co-occurrence of keywords was carried out, as shown in Fig. 4. For practical reasons, keywords that appear at least 3 times in the records considered were included. As can be seen, there are 7 clusters of keywords around the subject matter.

Cluster 1, in light blue, is headed by the word automation, agricultural robot, gas-chromatography and energy. In the context of viticulture, agricultural robots automate labor-intensive tasks such as pruning, harvesting and monitoring vineyard conditions, thereby increasing efficiency and reducing manual labor [51]. Also, gas chromatography is essential for analyzing wine composition, including aroma and flavor compounds, which are crucial for quality control and inclusion of the keyword energy can be linked to the growing concern for energy-efficient practices in wine production, where automation technologies can play an important role in reducing energy consumption and optimizing resource utilization [36].

Cluster 2, in red, is headed by the word grape, liquid, ethanol, acetic-acid bacteria and spectroscopy. This cluster covers the transformation of grapes into wine, focusing on the chemical composition of the liquid, such as ethanol production during fermentation. On the one hand, acetic acid bacteria are a concern in winemaking because of their role in wine spoilage, leading to unpleasant vinegar flavors [47]. On the other hand, spectroscopy is an essential analytical tool to evaluate wine composition, including the detection of ethanol and other chemical components, which is crucial for quality control and to ensure the consistency of the final product [11].

Cluster 3, in pink, has as main banners the words fermentation, design and amperometric glucose. This group emphasizes the design of fermentation technologies and control systems, such as amperometric sensors for glucose monitoring, as such monitoring is vital to control the fermentation process and ensure that sugars are properly converted into alcohol and other desired end products [62]. In this context, automation is about optimizing and controlling the fermentation process for consistent, high quality wine production [20].

Cluster 4, in yellow, is mainly represented by the keywords bottle storage, samples, low-cost and detectors. Automated bottle storage systems help manage large inventories, ensure optimal aging conditions and track wine provenance [22]. Samplers and detectors refer to automated sampling and detection systems for quality control, which ensure that each bottle meets the desired standards before reaching consumers [9], and the emphasis on the keyword low cost indicates that the aim is to make these technologies accessible and economically viable for wineries of different scales [23].

Cluster 5, in lilac, is headed by the keywords: computer vision, image processing, cork and neural networks. These technologies can be used for a variety of purposes, such as inspecting and sorting grapes, detecting defects in corks, and even analyzing wine color and clarity [59]. In this sense,

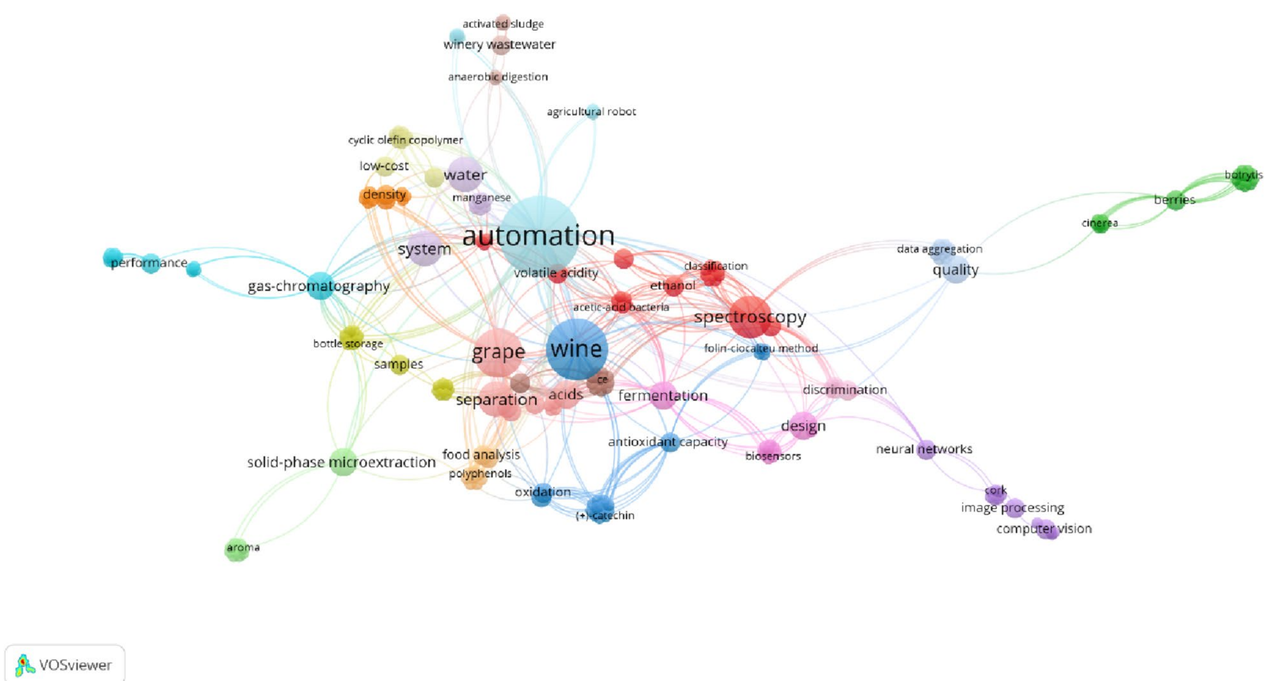


Fig. 4 Network map on the co-occurrence of keywords. Source: elaborated on the basis of WoS and VOSviewer

image processing and neural networks improve the accuracy and efficiency of these tasks, contributing to overall quality control and process optimization [16].

Cluster 6, in light green, is led by the keywords: aroma and solid-phase microextraction. Solid-phase microextraction is a method used to extract volatile compounds from wine, which are fundamental to its aromatic profile [45]. Automation in this field implies the development of high-performance, accurate and consistent methods of aroma analysis, which would contribute to the standardization of the sensory characteristics of wine [50].

Cluster 7, in dark green, is composed of cinerea, berries and botrytis. Automation in this context may involve the development of precision agriculture tools for monitoring and managing vineyard health, using data analytics and machine learning to predict and control the spread of such diseases, thereby ensuring the health and quality of the grapes [26].

The analysis of the keywords is complemented by the study of their use over time, In this regard, Fig. 5 shows that the most commonly used keywords currently used are computer vision, data aggregation, life cycle assessment, precision viticulture, extreme learning machine and collaborative platform.

First, computer vision embodies the integration of artificial intelligence and image analysis, enabling accurate monitoring of grape maturity, disease detection and yield estimation, its growing importance representing a move towards more efficient, data-driven vineyard management [68]. Second, data aggregation complements it by amalgamating diverse data sets—from weather conditions to vine health metrics—to facilitate informed decision making, given that, in an industry where subtle environmental variations can significantly influence grape quality, the ability to synthesize broad data sets into actionable information can enable optimization in the use of resources and maximization of yield quality [39]. Third, life cycle assessment emerges as another fundamental concept, underscoring the industry's growing concern for environmental sustainability, since, by assessing the environmental impact of wine production from vine to bottle, this methodology helps identify areas for improvement, whether in energy use, water management or carbon footprint reduction [19]. Fourth, precision viticulture stands out as a testament to the evolving nature of viticulture, emphasizing the use of technology to adapt vineyard practices to the specific conditions of each plot [8]. This method uses advanced technologies such as GPS, remote sensing and Internet of Things (IoT) devices to achieve optimal grape quality and sustainable farming practices, allowing to improve not only wine quality, but also ensures more environmentally friendly and economically viable operations [56]. Fifth, extreme machine learning, a type of artificial intelligence, indicates the industry's move towards innovative and efficient computational models for problem solving, being applied to various aspects of wine production, from predictive analysis in vineyards to quality control in wineries [6]. Sixth, the current use of the keyword collaborative platforms reflects a digital transformation in the wine industry, which facilitate communication

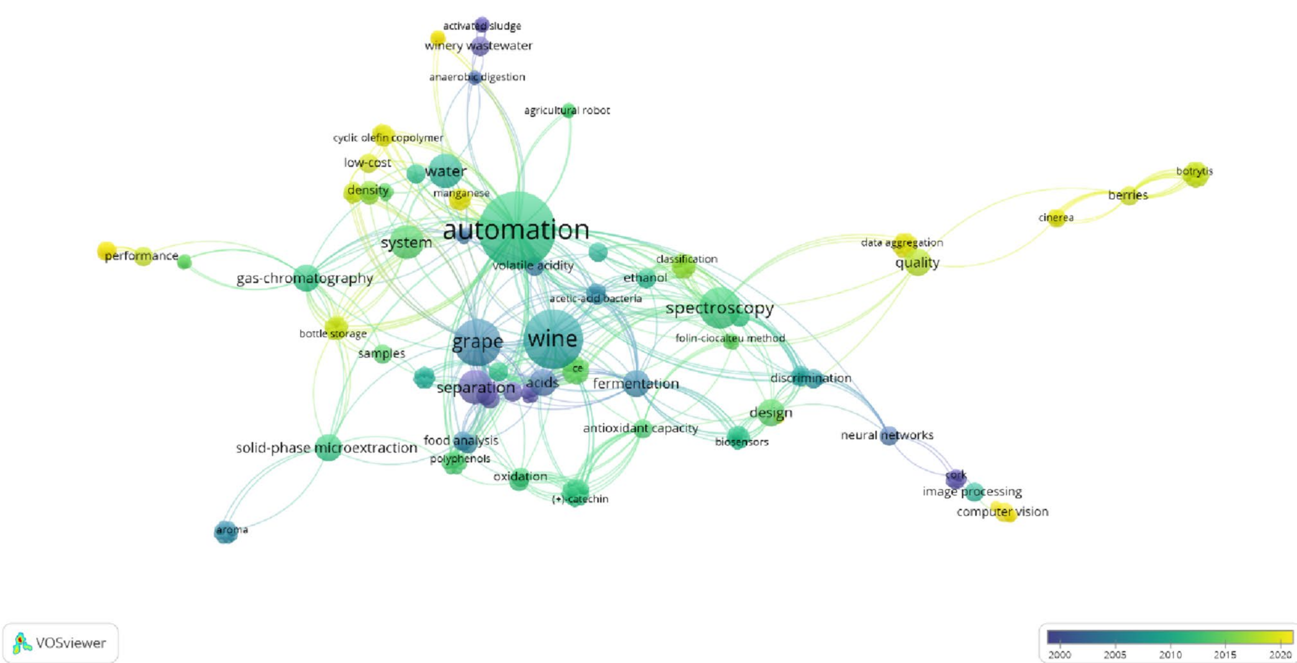


Fig. 5 Overlay map of the co-occurrence of keywords. Source: elaborated on the basis of WoS and VOSviewer

and data sharing between the various stakeholders, fostering a more integrated and transparent supply chain [5].

Table 2 displays the articles that have collected the highest total number of citations both globally and locally. Global citations, on the one hand, refer to the cumulative citations that a given article has obtained from any given area and location. On the other hand, local citations are the citations that each individual article has acquired from other articles within the analyzed repository. Furthermore, normalized total citations are the number of citations attributed to a research article or author, corrected for the number of years since publication and the average number of citations received by articles in the same field and time period. This metric takes into consideration variances in citation practices between fields and time periods, as well as the temporal aspect of citation influence. As can be observed, among the 10 most cited articles globally and among the literature analyzed, four publications coincide. These correspond to the research by Chilla et al. [12], Chang et al. [10], Torrijos and Moletta [67] and Ruíz et al. [53].

With regard to the main institutions analyzing the subject (see Table 3), it can be seen that the universities that lead the research on automation in the wine industry are University of Cadiz, University of Castilla La Mancha, University of Cordoba and University of Milan (with 3 articles each). Thus, of the top institutions in terms of scientific production on the subject, Spain and China are the countries with the largest number of institutions (tied with 3). This is related to the data shown in Fig. 6 on production by country, given that the Spain is the country with the highest scientific production on the topic under study (15 articles), followed by Italy (10), Chile (6 articles) and China (5 articles).

As for the classification of authors, Table 4 shows the most prominent authors according to the number of articles published. As can be seen, Barroso C, Guillen D, and Perezbustamante J, are the authors with the highest scientific production on the subject with 3 articles, followed by De Castro M, Moletta R, Pérez-Correa J, Pérez-Correa J, Sánchez-Rojas J and Torrijos M (with 2 articles each author). Figure 7 also shows how the main authors on the subject are organized into 13 collaborative clusters, being the one formed by Barroso C, Guillen D and Perezbustamante J. the cluster with the greatest weight in terms of jointly published articles.

After the bibliometric analysis, in which the literature under study was examined quantitatively, a systematic analysis of the research was carried out. Thus, as can be seen in Table 5, the objective of the research, its methodological

Table 2 Most cited papers (globally and within dataset)

Most cited papers (globally)			
Paper	TC	TC per Year	Normalized TC
Santos T, 2020, Comput Electron Agr	129	32,25	1,00
Mirnaghi FS, 2013, J Chromatogr A	57	5,18	2,34
Torrijos M, 1997, Water Sci Technol	51	1,89	1,74
Kritsunankul O, 2009, Talanta	40	2,67	1,00
Ruíz C, 2002, Water Sci Technol	37	1,68	1,00
Pinto PCAG, 2005, Anal Chim Acta	37	1,95	2,11
Toledo J, 2018, Sensor Actuat B-Chem	37	6,17	1,35
Chilla C, 1996, J Chromatogr A	36	1,29	1,22
Chang SH, 1997, IEEE T Neural Networ	35	1,30	1,19
Rist F, 2018, Sensors-Basel	35	5,83	1,28
Most cited papers (within dataset)			
Document	LC	GC	Normalized LC
Guillen DA, 1996, J Chromatogr A	1	23	0,78
Torrijos M, 1997, Water Sci Technol	1	51	1,74
Jiménez-Márquez F, 2014, Microsyst Technol	1	13	1,44
Chilla C, 1996, J Chromatogr A	0	36	1,22
Guillen DA, 1997, Quim Anal	0	2	0,07
Chang S, 1997, IEEE T Neural Networ	0	35	1,19
Ruíz C, 2002, Water Sci Technol	0	37	1,00
De Castro Mdl, 2003, J Aoac Int	0	9	1,00
Komes D, 2005, Vitis	0	12	0,69
Pinto Pcag, 2005, Anal Chim Acta	6	37	2,11

Source: own elaboration based on Bibliometrix®

TC total citations, *LC* local citations, *GL* global citations

Table 3 Most prolific institutions (institutions with more than two records)

Rank	Affiliations	Location (Country)	Articles
1	University of Cadiz	Spain	3
2	University of Castilla La Mancha	Spain	3
3	University of Cordoba	Spain	3
4	University of Milan	Italy	3
5	San Jose State University	USA	2
6	Moutai Institute	China	2
7	National Institute of Biological Sciences	China	2
8	National Tsing Hua University	China	2
9	Palacký University Olomouc	Czech Republic	2
10	Pontificia Universidad Católica de Chile	Chile	2
11	Universita di Bologna	Italy	2
12	University of Bonn	Germany	2

Source: own elaboration based on WoS

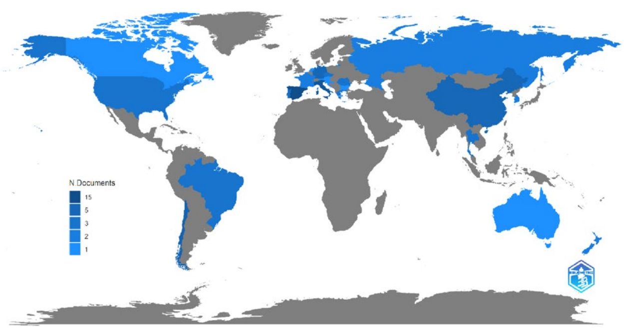


Fig. 6 Scientific production by country. Source: own elaboration based on Bibliometrix®

Table 4 Ranking of leading authors (authors with more than two records)

Rank	Authors	A. P	Rank	Authors	A. P
1	Barroso C	3	5	Moletta R	2
2	Guillen D	3	6	Pérez-Correa J	2
3	Perezbustamante J	3	7	Sánchez-Rojas J	2
4	De Castro M	2	8	Torrijos M	2

Source: own elaboration based on Bibliometrix®

A. P. articles published

approach, the research context and the phase of the wine value chain on which the study is focused were examined. The results show the preponderance of the quantitative versus qualitative methodological approach, the selection of a global framework versus a specific wine context, as well as the greater study of automation in the wine production phase within the wine value chain, versus the viticulture and wine distribution phase. Likewise, by analyzing the content of the articles, three lines of research were identified in relation to the subject matter under study. The first block of research focuses on the development of automated methods to improve sample preparation, detection and analysis of compounds, especially polyphenolics, in wines. There is growing interest in the use of technologies such as high-performance liquid chromatography and mass spectrometry to analyze compounds in wines, suggesting a focus on improving accuracy and efficiency in wine chemical analysis. Second, there is a block of papers focused on identifying efforts to develop automated systems for sorting cork quality and for monitoring fermentation and aroma production in wine, indicating an interest in optimizing product quality and production process efficiency. The third block of research focuses on sustainability and efficient resource management in the wine industry, with a notable trend towards the implementation of sensors and optoelectronic devices for real-time monitoring of viticulture and winemaking processes. These technological tools provide accurate and constant data, facilitating a more efficient and sustainable management of resources, as well as an improvement in the quality of the final product. This focus on the integration of automation and computerization reflects a paradigm shift in the wine industry, given that, by prioritizing both product quality and the efficiency and sustainability of production processes, a new horizon is taking shape for vine cultivation and wine production, where advanced technology plays a crucial role in harmonizing winemaking excellence with environmental responsibility.

Conclusions and future research agenda

This research examines the structure of knowledge on automation in the wine industry, becoming a valuable resource for novice and experienced academics interested in exploring the development of the scientific literature on the subject, as well as for wine managers to learn about

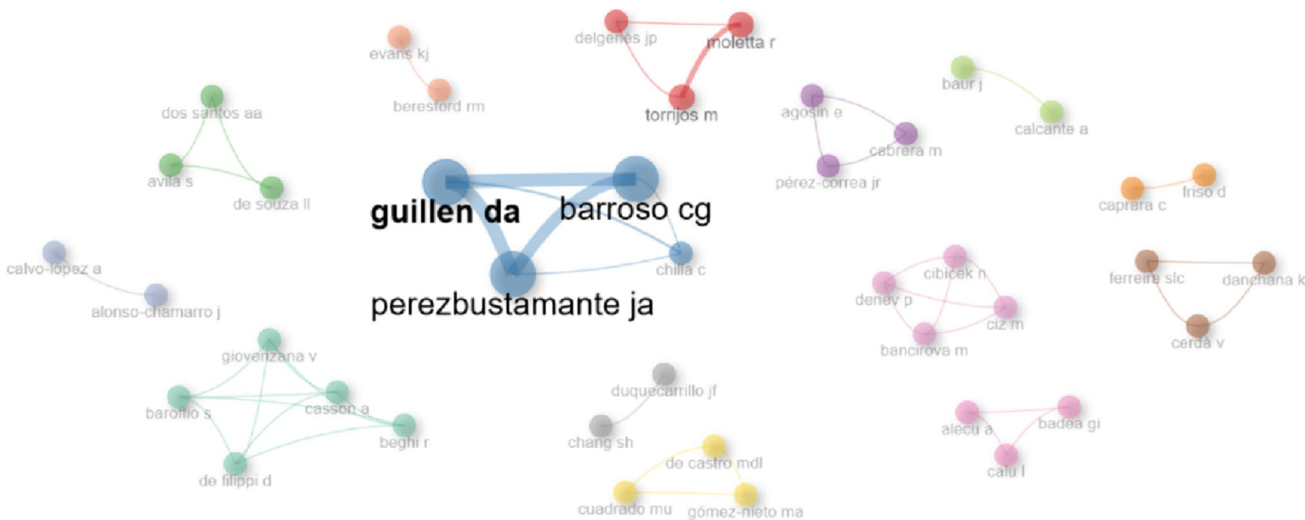


Fig. 7 Author collaboration network. Source: own elaboration based on Bibliometrix®

modern trends in automation and, if appropriate, to integrate these innovations in the different stages of the winemaking process.

In order to advance in the research field of automation in the wine industry, future directions are outlined that address emerging and still unexplored domains in relation to the analyzed topic. First, research is proposed on the integration of advanced robotics in viticulture and enology, with special interest in the development of drones and autonomous robots for pruning, harvesting and monitoring of vine and soil conditions, with the aim of increasing the precision of these fundamental operations. Second, it is proposed to examine the application of nanotechnology in winemaking, proposing the use of sensors for real-time monitoring of soil quality, and the development of nanomaterials to optimize wine preservation and packaging, thus opening new avenues for quality control and wine shelf-life extension. Third, it is also suggested to explore the potential of augmented and virtual reality to enrich the wine tasting experience and in the training of winery personnel, offering sensory simulations and virtual environments for learning winemaking techniques. Fourth, it is proposed to examine the role of artificial intelligence in predicting market trends and wine personalization, using advanced algorithms to adapt products to consumer preferences and market demands. Finally, fifth, it is proposed to investigate energy sustainability in the wine industry, exploring specific renewable energy solutions and wine production methods with lower environmental impact, thus marking a path towards innovation and sustainability in the sector. Thus, while the identification of the current research fronts shown in the results and the future research agenda proposed in this section enable to address RQ 1, the quantitative examination of the research examined presented in the results section enables to answer RQ 2.

This research contributes significantly to the theoretical, practical and policy domain in the study of automation in the wine industry. From a theoretical perspective, first, it provides a comprehensive overview of the scientific literature devoted to the analysis of automation in this sector; second, it facilitates researchers to identify key organizations and geographic regions linked to the topic, thus promoting research visits and collaboration on joint projects; third, it makes it possible to locate other experts with whom to collaborate and, potentially, to organize specialized conferences; fourth, it provides guidance in the selection of appropriate journals and publishers for the dissemination of research results; and fifth, the study the study sets the stage for academics to identify emerging trends in the automation of the wine value chain, thus enriching the existing theoretical corpus and opening up new avenues for future research.

From a practical perspective, this study highlights the importance for winery managers to recognize the potential of automation to improve efficiency and quality in wine production. Automation of processes such as fermentation monitoring, cork selection and wine component analysis can increase the accuracy of the final product, vitally important in an industry where quality and product characterization are critical to market success. In addition, the study highlights the crucial role of automation in the sustainability of the wine industry, urging winery managers to consider adopting automated technologies for efficient resource management and minimizing environmental impact. Further practical implications focus on the integration of artificial intelligence and data analytics in winemaking decision-making, as the ability to process large volumes of data to predict market trends, optimize production processes and improve vine disease management opens up new possibilities for competitiveness in an

Table 5 Analysis of the scientific production examined in the literature review

No	Authors	Journal	Research objective	Methodology	Country/Region	Wine value chain
1	Guillén et al. [24]	Journal of Chromatography A	To automate sample preparation for HPLC analysis of polyphenolic compounds in sherry wine, improving recovery and repeatability values	Quantitative	Spain	Winemaking
2	Chilla et al. [12]	Journal of Chromatography A	To develop a new method for preconcentrating and analyzing phenolic compounds in sherry wine using on-line SPE-HPLC with diode array detection	Quantitative	Spain	Winemaking
3	Guillén et al. [25]	Quimica Analitica	To apply a previously developed method for monitoring phenolic compounds during the fermentation of sherry must, using automated SPE and HPLC–DAD analysis	Quantitative	Spain	Winemaking
4	Torrijos and Moletta [67]	Water Science and Technology	To demonstrate a depollution process for treating effluents from small wineries using a sequencing batch reactor with temporary storage facilities	Quantitative	Global setting	Winemaking
5	Chang et al. [10]	IEEE Transactions on Neural Networks	To develop an automated cork stopper quality classification system using morphological filtering, contour extraction, and a fuzzy-neural network to improve accuracy and reduce costs	Quantitative	Mediterranean countries	Winemaking
6	Ruiz et al. (2002)	Water Science and Technology	To evaluate the effectiveness of an anaerobic sequencing batch reactor in treating winery wastewater, focusing on biogas production, COD removal, and kinetics of VFA removal	Quantitative	Global setting	Winemaking
7	Luque de Castro et al. [35]	Journal of AOAC International	To review the use of analytical pervaporation in enology, assessing its advantages and comparing it with standard methods for determining analytes in wine	Qualitative	Global setting	Winemaking
8	Komes et al. [31]	Vitis	To compare three methods for preparing white wine samples for gas chromatography, focusing on replacing liquid–liquid extraction with HS-SPME and SBSE	Quantitative	Global setting	Winemaking
9	Pinto et al. [49]	Analytica Chimica Acta	To develop an automatic system for evaluating the relative antioxidant capacity of wine samples using two different analytical procedures	Quantitative	Portugal	Winemaking

Table 5 (continued)

No	Authors	Journal	Research objective	Methodology	Country/Region	Wine value chain
10	Pinheiro et al. [48]	Analytical Chemistry	To monitor the bioproduction of complex aroma profiles in muscatel wine must fermentation using an integrated pervaporation-electronic nose system, overcoming ethanol interference	Quantitative	Global setting	Winemaking
11	Cuadrado et al. [17]	Analytica Chimica Acta	To develop an automated method for determining laccase activity in musts and wines, offering a new tool for assessing Botrytis cinerea infection	Quantitative	Global setting	Winemaking
12	Jan et al. [28]	Food control	To explore the use of ultrasound in measuring sugar and alcohol concentrations in hydroalcoholic solutions, mimicking fermenting musts in the Chilean wine industry	Quantitative	Chile	Winemaking
13	Osorio et al. [42]	Journal of Food Engineering	To develop a cost-effective soft-sensor for on-line estimation of distillate ethanol concentration in brandy production using temperature measurements	Quantitative	Chile	Winemaking
14	Kritsunankul et al. [32]	Talanta	To develop an automated FID-HPLC system for simultaneous determination of six organic acids in wine, with online dialysis sample pretreatment	Quantitative	Thailand	Winemaking
15	Albanese et al. [2]	IEEE Transactions on Instrumentation and Measurement	To develop an automated system for monitoring biological processes in winemaking using amperometric biosensors in flow injection analysis	Quantitative	Global setting	Winemaking
16	Rosaldini and Ceccarelli (2012)	Geomedia	To address the need for automation, computerization, and traceability in agricultural and wine-devoted farms by developing a GIS-based agrarian wine cellar information system	Quantitative	Global setting	Viticulture
17	Jakubec et al. [27]	Journal of Agricultural and Food Chemistry	To develop and test a method for analyzing total antioxidant capacity and total phenolic content in wines using microdialysis online-coupled with amperometric detection	Quantitative	Global setting	Winemaking
18	Oberti et al. [40]	Journal of Agricultural Engineering	To develop a robotic system for selective spraying of grapevine diseases, reducing pesticide use by targeting only infected areas	Quantitative	European Union countries	Viticulture

Table 5 (continued)

No	Authors	Journal	Research objective	Methodology	Country/Region	Wine value chain
19	Pezzi et al. (2013)	Journal of Agricultural Engineering	To conduct a technical and economic evaluation of the maceration process in red grape production for everyday wine	Quantitative	Global setting	Winemaking
20	Mirnaghi et al. [37]	Journal of Chromatography A	To optimize an automated 96-thin-film SPME system for high-throughput analysis of phenolic compounds in wine, berry, and grape samples using LC–MS/MS	Quantitative	Global setting	Winemaking
21	Jiménez-Márquez et al. [29]	Microsystem Technologies	To develop an optoelectronic device for automating the monitoring of wine fermentation kinetics and maceration, enhancing the quality-cost ratio in winemaking	Quantitative	Global setting	Winemaking
22	Teodor et al. [64]	Chemical Papers	To characterize wine samples in ceramic pots using various methods, focusing on chemical and mineralogical aspects, and identify potential biomarkers for wine residues in archaeological pottery	Quantitative	Global setting	Winemaking
23	Mirzoian and Ammann [38]	Journal of AOAC International	To develop and validate a direct injection LC/MS/MS method for determining the pesticide oxadixyl in wines, with minimal sample preparation and high throughput	Quantitative	Global setting	Viticulture
24	Lee et al. [33]	International Journal of Food Science & Technology	To develop an automated Folin-Ciocalteu method for measuring total phenolic content in wine, aiming for faster processing, reduced errors, and waste minimization	Quantitative	Global setting	Winemaking
25	Yakuba et al. [70]	Journal of Analytical Chemistry	To evaluate wine quality using discriminant analysis based on volatile substance concentrations and taste test results, aiming to compare with expert evaluations	Quantitative	Global setting	Winemaking
26	Khalafyan et al. [30]	Journal of Analytical Chemistry	To develop a model for predicting wine quality based on concentrations of volatile substances and organoleptic ratings, using statistical-probability simulation methods	Quantitative	Global setting	Winemaking
27	Toledo et al. [66]	Sensors and Actuators B: Chemical	To enhance wine fermentation monitoring by designing an AlN-based piezoelectric microresonator for in-line tracking of grape must fermentation, improving automation and accuracy	Quantitative	Global setting	Winemaking
28	Rist et al. [52]	Sensors	To develop a high-precision phenotyping pipeline using 3D scanning for assessing grapevine bunch architecture traits in breeding programs	Quantitative	Global setting	Viticulture

Table 5 (continued)

No	Authors	Journal	Research objective	Methodology	Country/Region	Wine value chain
29	Yang et al. [71]	Analytica Chimica Acta	To optimize the kinetic process of continuous liquid–liquid extraction for real-time analysis of volatile wine components, using an Arduino-controlled system coupled with mass spectrometry	Quantitative	Global setting	Winemaking
30	Hill et al. [26]	Phytopathology	To predict botrytis bunch rot risk in wine-grape production using automated analysis of disease, weather, and vine phenology data across multiple regions and seasons	Quantitative	Global setting	Viticulture
31	Phansi et al. [46]	Food chemistry	To develop a multisyringe flow injection analysis system for the automatic spectrophotometric determination of total iron in wine	Quantitative	Global setting	Winemaking
32	Mylonas et al. [39]	Information	To develop a model for an aggregation platform enhancing smart agriculture in viticulture, enabling improved data annotations and enrichment through AI automation and human–computer collaboration	Qualitative	Global setting	Viticulture
33	Sández et al. [55]	Analytica Chimica Acta	To design, construct, and evaluate a low-cost microanalyzer for determining the titratable acidity content of wine using a continuous flow system with optical detection	Quantitative	Global setting	Winemaking
34	Santos et al. [57]	Computers and Electronics in Agriculture	To demonstrate the use of convolutional neural networks for detecting, segmenting, and tracking grape clusters in orchards using proximal sensing and affordable cameras	Quantitative	Global setting	Viticulture
35	Giovenzana et al. [22]	Journal of Agricultural Engineering	To analyze an automated yeast nutrition management system for alcoholic fermentation in wineries, assessing its environmental, management, and economic performance	Quantitative	Italy	Winemaking
36	Signorini et al. [63]	Horticulturae	To assess the economic feasibility of grape vineyards in the Midwest U.S.A. by analyzing different production scenarios using sample budgets and survey data	Quantitative	United States of America	Viticulture
37	Apostolidis et al. [3]	Data	To create a public image dataset for grapevine canes segmentation to facilitate the automation of grapevine pruning using computer vision and image processing methods	Quantitative	Global setting	Viticulture

Table 5 (continued)

No	Authors	Journal	Research objective	Methodology	Country/Region	Wine value chain
38	Xiao et al. [69]	Mathematical Problems in Engineering	To develop a multimotor drive control method based on machine vision for an upper-retort-robot to automate wine brewing, particularly for military use in cold regions of China	Quantitative	China	Winemaking
39	Legun et al. [34]	Agriculture and Human Values	To explore agricultural managers' perceptions of automation potential in relation to expertise required for work on apple orchards and winegrape vineyards in Aotearoa New Zealand	Qualitative	New Zealand	Viticulture

Source: own elaboration

ever-changing marketplace. Ultimately, this study emphasizes the importance of senior management commitment to training and continuing education in the wine industry, because as automation and new technologies gain ground, it is crucial that wine professionals are equipped with the skills and knowledge necessary to use these tools effectively. This would not only improve the efficiency of wine production, but also ensure that the industry can evolve and adapt to technological advances.

From the policy implications angle, this research underscores the need to formulate policies that encourage innovation and the adoption of automated technologies in the wine industry. This would involve incentives for research and development, as well as financial support for wineries, especially small and medium-sized enterprises, to adopt new technologies. It would be also crucial to promote the regulation of automation and artificial intelligence in the wine industry, covering aspects such as security, data privacy and ethics in the use of artificial intelligence. Policies should ensure that the adoption of these technologies is done in a responsible and transparent manner, protecting both consumers and producers. Similarly, policy makers could direct their efforts to promote sustainable practices in viticulture, such as reducing the use of pesticides and efficient water management, supported by automation technologies, which would also imply the need for policies that encourage the adoption of cleaner and more environmentally friendly production practices. Moreover, it suggests the need to consider how automation affects the competitiveness of the wine industry in the global market and how national interests can be balanced with the need to compete in an increasingly technologically advanced marketplace. In this way, the theoretical, practical and policy implications derived from this research provide answers to RQ 3.

While this bibliometric and systematic literature review offers valuable insights, there are certain limitations that must be acknowledged. On the one hand, while the review effectively highlights key research themes and trends, it does not extensively explore the practical implementation and challenges of automation within the wine industry. This gap suggests an opportunity for further research, particularly through a multiple case study approach to better understand how automation impacts operational efficiency in wineries. On the other hand, the analysis in this review is based solely on the Web of Science Core Collection database. While this database is renowned for its comprehensive and high-quality coverage, relying on a single database might result in missing significant articles that are not indexed within it. To address this, future research should aim to expand the bibliometric analysis by including a variety of databases, thereby ensuring a more comprehensive coverage of the scientific literature in this field.

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