Research trends in the oenological and viticulture sectors

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Abstract

Background and Aims: The purpose of this study was to analyse the trend of the scientific evolution of the oenological and viticulture sectors by accounting for the peer-reviewed articles written in the English language as retrieved from the Scopus database.

Methods and Results: The scientific research in both sectors was active in 2020 with 2000–2500 publications per year. Owing to their long tradition in wine production, Italy, Spain and France were the main publishing nations, even if other nations, such as the USA, China and Australia, started to be interested in wine production. In the oenological sector, the highest number of articles were published by researchers working in French and Spanish highly specialised institutions. Over the 1950–2020 period, the *Journal of Agricultural and Food Chemistry* has been the most cited. Over the last 5 years, other journals, such as *Food Chemistry*, *Molecules* and *Oeno One*, have gained reputation; furthermore, from the bibliographic map analysis the antioxidant activity of anthocyanidin and polyphenols has been the topic most studied, followed by the genetics of grapevine and yeast, and methods of analysis to determine volatile, nutritional and anti-nuisance compounds.

Conclusions: In contrast to the beer sector, current wine research has probably taken for granted the negative implications of the consumption of wine on human health and has given rise to no market targets for low-alcohol or alcohol-free alternatives.

Significance of the Study: Despite the spreading of digital techniques in grapegrowing, the present wine technology appeared to be less receptive to the upcoming digital transformation of the food and beverage industry.

Keywords: *bibliometric indexes, bibliometry, citations, grape and wine research publications*

Introduction

Bibliometric and bibliographic studies are generally used to understand past, present and future trends in a research field by analysing a large number of published papers. These studies have increased over the last 20 years because of the continuous digitisation and collection of meta data from scientific publications in databases.

The global influence of the grape and wine industry in terms of production, cultivated area and trade is well known. In 2020 world production of wine was estimated between 253.9 and 262.2 million hL (MhL), the great majority (159.0 MhL) produced in the European Union, the cultivated area was 7.4 Mha (3.2 Mha in European Union) and the world wine export market was about 106 MhL and €32 billion (Organisation Internationale de la Vigne et du Vin 2020). Owing to the economic relevance of the industry, there has always been a significant scientific interest in novel technological innovations and cultivation techniques, grape disease resistance and wine characterisation, as well as in wine and health implications.

Some bibliometric studies have analysed the scientific literature concerning the sensory properties and quality of wines (Aleixandre-Tudo et al. 2019) and to highlight the evolution of this sector in emerging countries (Aleixandre et al. 2013). Scientific productivity and collaboration in viticulture and oenology in Latin American countries (Aleixandre et al. 2013) or at the global level (Aleixandre et al. 2015) have also been assessed.

When extracting data from one of the citation indexes, a proper search key must be used, otherwise the results obtained cannot be reproduced or verified by other authors in a scientific way. In the oenology and viticulture sectors many authors referred to a query string (research keys) developed by Glänzel and Veugelers (2006) based on the Web of Science (WoS) platform. Jamali et al. (2020) showed how the use of four different search keys influenced the numerosity of the resulting database and highlighted how the search string affected the results obtained. As suggested by Glänzel and Veugelers (2006) and Jamali et al. (2020), the inclusion in the search string of the total number of publications in specialised journals, that is the *American Journal of Enology and Viticulture*, *Australian Journal of Grape and Wine Research*, *Vitis* and *South African Journal of Enology and Viticulture*, increased the overall number of articles included in the database by the small proportion of 0.58%, increasing the 2334 items already retrieved using the first query string by just 143 new documents. This procedure, however, together with the exclusion of selected subject areas appeared to be risky for following reasons:

- Some of the specialised journals might also account for research related to other fermented or distilled beverages, such as mead and cider.
- The addition of all the publications of such journals against those of not specialised journals might be incorrect because the experimental error related to the search keys should be equally distributed over all the journals considered.
- The search keys should be valid regardless of the journal type and subject area accounted for.

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- Finally, the inclusion of all the publications of the journals mentioned above in the relative database might give rise to an additional experimental error, especially if a separate analysis regarding grape or wine is considered.

One of the objectives of the wine sector research today is to meet the needs of consumers, who are showing increased interest towards environmental issues and about the ways used to make the wine they buy, as well as to guarantee at the same time a high level of wine quality. In addition to the introduction of regulations much stricter than in the past, such new perspectives have led to the development of alternative production methods to improve the eco-sustainability and healthiness of the wine products, namely organic wines, vegan wines, biodynamic wines, orange wine, eco-sustainable packaging and waste upgrading.

The main aim of the work was to review the global historical trend in grape and wine research to identify the present research opportunities and emerging trends and to uncover the key drivers of change in the near future.

Materials and methods

Bibliometric analysis of scientific literature

To analyse bibliometrically the world scientific production on wine and grapes, the Scopus search engine was consulted on 10 March 2021 to retrieve the related database for peer-reviewed articles published from 1950 to 2020 (included). This choice implied the exclusion of non-peer-reviewed articles, as well as some proceedings, communications and patents, which were out of the scope of this work. Despite the WoS of Thomson database had not been consulted in this work, a few studies that compared the performance of WoS and Scopus did not recommend any of them as the better choice. Sánchez et al. (2017) carried out a bibliometric analysis of publications on wine tourism and maintained that such databases were complementary and not mutually exclusive. Moreover, the result of the analysis was dependent on the research area and time period examined (Neuhaus and Daniel 2008), as well as on the different time periods covered by each database (Tabacaru 2019). The database extracted from the Scopus database can be strongly influenced by the search string used. Indeed, such a string represents the most important tool to extract reliable results for the purpose of a bibliometric analysis. In this specific case, owing to the strict correlation between the areas of oenology and viticulture, three databases were extracted by using three different search strings. A first database regarding the scientific publications of the oenology sector [Wine-database (W-database)] was constructed using a query string containing terms directly related to the world of wine and including its production technologies. It was labelled as Group 1 'Wine', as shown in the electronic supplement (Table S1). A second database [Grape-database (G-database)] was obtained by using specific terms related to grapes only, this being labelled as Group 2 'Grape'. A third database was extracted using a search string obtained by combining both Groups 1 and 2. These strings were also composed of terms (reported as Group 4 'shared excluded'), that allowed the exclusion of numerous scientific publications on topics different from those studied here, sharing the use of some terms (e.g. Port-Wine stains) or idioms (e.g. old wine in new bottles). In the search string, the presence of such terms in the title directly excluded the publication from the final database, as well as the simultaneous presence of one of the pairs of two terms present in Group 5. Obviously, as in any experimental determination, it is practically impossible to produce a final database free from errors, because the 'perfect search string' is theoretically unachievable, and background noise will always be present. Databases can be obtained by accounting for the title only, or title and abstract. The first hypothesis allowed the creation of a database with publications strictly related to the field of research, but at the same time it limited their number. For example, a publication about wine might not necessarily use the term *wine* (or one of those present in Group 1) in the title. Differently, when searching terms in the abstract of the scientific publications, the numerosity of the database increased at the expense of the appropriateness of the articles collected to the topic of concern. For instance, a scientific article could deal with a subject completely different from wine, but it might mention this term as a reference or example in its abstract. To reduce this type of experimental error and, at the same time, to be able to retrieve the greatest number of articles for a better representation of the subject under study, a 'combined' search was carried out, that is:

- Research in the field 'TITLE' for terms closely related to the research themes included in Groups 1 and 2; and
- research in the field 'ABSTRACT' using the basic terms 'Wine' and 'Grape' and matching each one (through the Scopus operator 'AND') with the terms of Group 3 for W- and G-databases, respectively.

In this way, the various databases included scientific works which had the terms of Groups 1 and 2 in the title, but also those which had the simultaneous presence in the abstract of one of the terms 'Wine' or 'Grape' and one of the terms of Group 3, even if these terms were not included in the title.

The simultaneous presence of the two terms in the abstract of the scientific article allowed the identification of the research area in a quite univocal way and had the effect of including works that would have not been included when using the title search only. For an accurate description of the Scopus logical operators, refer to the Scopus Search Guide. Figure 1 reports a graphical representation of the query string formation. The search was limited to publications written in English, excluding many authors who wrote articles in their native language.

The resulting three databases (including: Title, Number of Citations, Year, Authors, Affiliations and Countries) were collected in .csv format and the data extracted were elaborated as follows:

- A *simple data collection* yielded quantitative and qualitative bibliometric analysis in the form of tables and graphs reporting the most publishing countries, affiliations, authors, journals and founding sponsors, as well as the number of citations per paper (CPP).
- An *abstract textual analysis* was used to highlight some of the most recurrent and studied terms in the articles of the databases obtained. A Python script (Anaconda 3) was used to analyse all the words present in the Abstracts extracted from the database, which were converted in a .txt file to obtain the frequency (occurrence) of the words listed in Table S2, these having been subdivided into five groups, namely Group A, B, C, D and E with terms identifying the main types of products, molecules or analytical procedures, some aspects of research, grape cultivars and grape diseases, respectively.

- The bibliometric mapping and clustering approach was used for map analysis (van Eck and Waltman 2010). Thus, some word publication maps were plotted using colour intensities proportional to the number of publications by means of the VOSviewer v. 1.6.5.0 software (freely available at www.vosviewer.com). This software was specifically developed for creating, visualising and exploring scientific bibliometric maps (van Eck and Waltman 2011). In such a visual map, strongly related terms are contiguous, while the weakly related ones are distant from each other. Only terms occurring at least 50 times were extracted from the retrieved publications. The next step was to identify clusters of related terms by means of a software applying clustering technique (van Eck and Waltman 2010, 2011). The assignment of terms to the same cluster depended on their co-occurrences in the *Title* and *Abstract* of the publications retrieved, terms often co-occurring were strongly related to each other and were automatically assigned to the same cluster. In contrast, terms with a low co-occurrence or no-occurrence at all were assigned to different clusters. A cluster made up of terms characterised by the same colour represented a research theme in which one or more research topics were identified. It is also important to note another intrinsic limitation of all bibliometric studies, especially when data are extracted from the *Title* and/or *Abstract*. Because not every single article can be individually assessed, a term word (i.e. health effect) related to quite an important topic can be frequently included in the *Abstract* of several papers, even if such articles not necessarily dealt with any medical study.

A Thesaurus file was also used to ensure consistency for different spelling of terms, and synonyms, and to omit those terms considered not relevant to the search (i.e. names of cities or countries). For instance, *grape pomace* or *grape skin* was termed *grape marc*.

Time horizon

Since the Scopus search was conducted in March 2021, publications related to the year 2021 were included in the analysis. For this year, however, not all publications were indexed by the Scopus database and therefore their total number was underestimated. For the same reason, the citation count excluded the 2021 publications. Scimago (https://www.scimagojr.com/) was used to extract information about journals.

It is worth noting that the database obtained did not include all the papers published in the field of this research paper; the data collected being intended to give a general picture of the world scientific research in the wine and viticulture area and not to draw up a ranking between countries, affiliations or authors. In general, a variable underestimation of the order of 10–15% in the data obtained might be considered, as roughly estimated by comparing the number of articles published by several authors as manually counted with that extracted from the database using the search keys mentioned above.

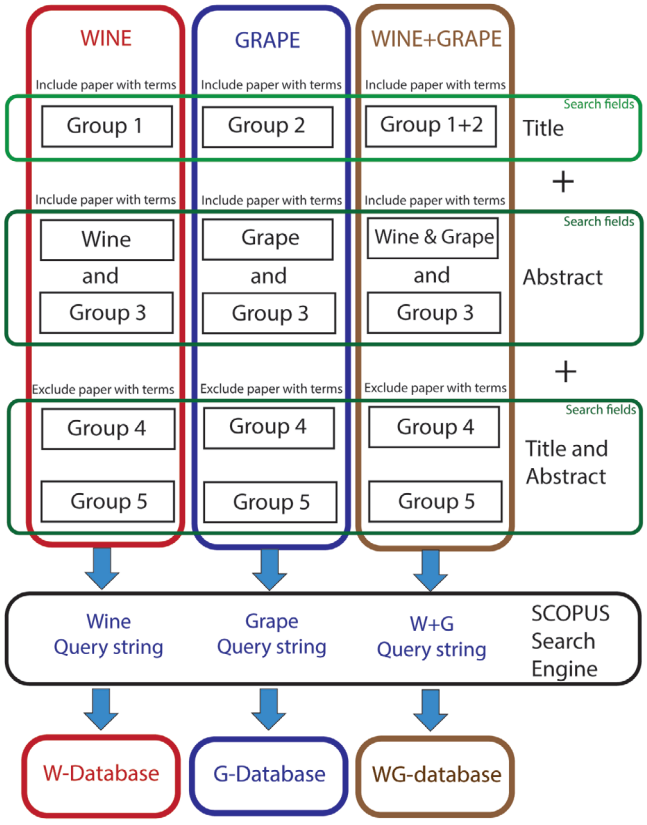


Figure 1. Schematic representation of logical formation of three query string and relative database.

Results and discussion

Bibliometric analysis

Sensitivity analysis. To improve the scientific value of this paper and to verify the variation of the data (number of research articles) collected, a sensitivity analysis was performed using the query strings including the terms presented in Group 1 and Group 3 for Wine, or Group 2 and Group 3 for Grape, in different search fields (i.e. Title, Title + Abstract), as well as the *excluded terms filters* (Groups 4 and 5) in Title + Abstract.

Table 1 reports the number of publications obtained using the title (TITLE) or title and abstract (TITLE ABS) as research fields. When the Abstract was included, there was an increase of +155, 176 and 151% in the number of articles present in the resulting databases, respectively. Obviously, this increase also led to a proliferation of documents not strictly related to the subject under study. Some of these were reduced when the *excluded term filters* were added to

Table 1. Sensitivity analysis in the Wine-, Grape- and Wine + Grape-databases for Title and Title + Abstract textual search, for the chosen query string (Title + Abs Comb) and for specialised wine journals.

Search field	Wine	Grape	Wine + Grape
TITLE	40 977	30 766	64 569
TITLE + ABS	63 541	54 307	97 685
TITLE + ABS + FILTER	35 579	34 535	57 822
TITLE + ABS + FILTER + SWJ	37 316	35 164	58 235

SWJ, specialised wine journals.

the search string (TITLE + ABS + FILTER). Thus, the final databases accounted for the following overall number of papers:

- W-database = 35 579;
- G-database = 34 535; and
- W + G-database = 57 822.

The W + G-database did not represent the arithmetic sum of W- and G-databases, because it derived from different search strings produced by coupling those used for the W- and G-databases. Some publications were included in both W- and G-databases. As suggested by Jamali et al. (2020), a further string, including all the papers published in the main specialised journals, for example *American Journal of Enology and Viticulture*, *Australian Journal of Grape and Wine Research*, *Vitis*, *South African Journal of Enology and Viticulture*, was added as shown in Table S3 for the three databases when considering the authors, affiliations and countries. The results showed that the differences found in terms of publication numerosity did not modify substantially the position of authors, countries and affiliations, this confirming that the query string used was reliable and/or that the inclusions of the specialised journals did not affect in a substantial way the results obtained, the associated information representing only a small part of the data stored in each database. At the same time, the approach used here did not exclude some subject categories, as that suggested by Glänzel and Veugelers (2006), as well as subsequent similar research, such as that excluding social science, arts and humanity, or dentistry. Potentially, this choice can result in much noise, but it is unavoidable if the primary aim is to incorporate the greatest number of possible articles for a truthful representation of a given field of search. The Scopus database catalogues the same article in more than one subject area; thus, well studied query strings, including the so-called 'shared terms' for the exclusion of the unrelated scientific publications, help avoiding some auto-imposed restrictions to attempt reducing the experimental error.

Trend in the number of publications per year. Figure 2 shows the trend in the number of publications per year, as extracted from the selected databases. It is evident that from 1970 to 1990 the average number of papers published each year was relatively low (84 ± 31, 64 ± 27 and 135 ± 51 for W-, G- and W + G-databases, respectively). From 1980 to 2000 there was an almost steady increase in the number of publications, which reached an overall number of 2336, 2619 and 3917 publications in 2020 for the W-, G- and W + G-databases, respectively. It should be noted that the trend in the number of publications obtained was quite similar for the wine (W) and grape (G) sectors. This might lead one to think that the two databases entered the same publications despite the use of two different search keys. As it will be seen below, the data extrapolated from such databases gave rise to different results, even if the two sectors exhibited quite a similar evolution in terms of the number of publications. Clearly, the evolution of the scientific research in the field of concern was directly correlated to the general increase in the number of scientific publications during the last 20 years, as shown in Figure 2, which shows the results of the database analysis.

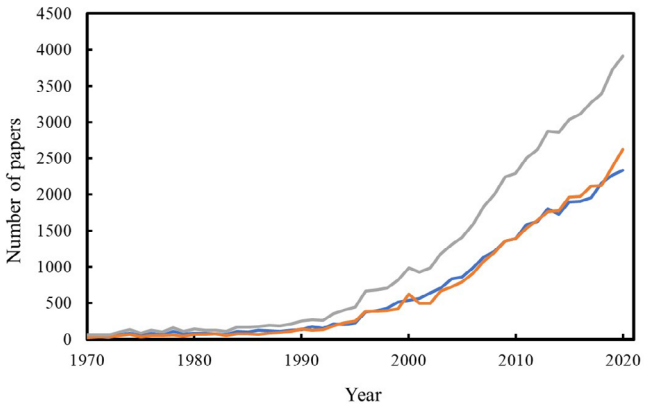


Figure 2. Annual distribution of the overall number of scientific research papers for Wine (——), Grape (——) and Wine + Grape (——) databases.

Publications distributed by country. Table 2 sets out the distribution of publications by country, these being organised in descending order with respect to the number of publications for two different time periods: 1950–2021 and 2010–2021. The number of publications in both research fields for the countries publishing the most was almost the same. By considering the total number of articles produced in the field of oenology from 1950 to 2020, Spain was the nation with the highest number of publications (5521); these representing 12.9% of the total. The USA was the second country, while Italy was third; their overall number of publications being 4397 and 4175, respectively. In the G-database, whereas the USA was in the first place with 5242 documents, the second and third positions were occupied by Italy (4552) and Spain (4006). By referring to the W + G-database, of the top 10 countries with the greatest overall number of publications six countries were European, while the remaining four practically represented all the other continents, for example USA, Australia, China and Brazil. except for Africa (South Africa being at the 16th place). In this ranking, the number of inhabitants per nation has a strong influence because it affects the number of researchers and research bodies/universities. For instance, by referring to the W + G-database and the 2010–2021 period, the list of the main publishing countries, that is Italy, Spain, China and USA, changed strongly when the number of publications was accounted for the per capita basis. In fact, by referring to the population data extracted from https://www.worldometers.info/world-population/population-by-country/, Spain was the first publishing country with 82.7 papers published per million inhabitants, followed by Italy (68.9), USA (8.2) and China (2.7). It can also be noted that Italy has held first place in the G- and W + G-databases from 2010 to the present. Another interesting fact was observed by comparing the 1950–2021 period with that of 2010–2021. Despite China being in fifth place in the W + G-database, it practically produced about 83% of the papers published over the last 10 years. In the last decade, there was a clear lack of interest in the grape and wine sector on the part of the US authors. In fact, from 2016 to 2020, they have produced only 33% of the total US papers published since 1950, while China, Spain and Italy produced 83, 52 and 59% of their overall papers published since 1950. Table S4 shows a detailed comparison among the documents produced by the first ten publishing countries during three different time periods, that is 2020–2016, 2020–2011 and 2010–2001, together with their proportion of the overall number of publications

relative to the wine sector retrieved throughout the period 1950–2020.

Number of citations per country. Table 3 shows the overall number of publications, and relative citations as well as the average number of citations per article (CPP), during the period 2016–2020, as extracted from the databases mentioned earlier.

The world average number of citations for scientific articles was of the order of 6.4. By accounting for the CPP values pertaining to the top five most publishing countries as extracted from for the G- or W-database (see Table 4),

Table 2. Distribution of publications by country organised in descending order with respect to the number of publications in the time periods, 1950–2021 and 2010–2021.

1950–2021							2010–2021					
	Wine		Grape		Wine + Grape		Wine		Grape		Wine + Grape	
Rank	Country	No.	Country	No.	Country	No.	Country	No.	Country	No.	Country	No.
1	Spain	5521	USA	5242	USA	8077	Spain	3355	Italy	3057	Italy	4166
2	USA	4397	Italy	4552	Spain	7490	Italy	2809	China	2930	Spain	3867
3	Italy	4175	Spain	4006	Italy	7014	USA	2394	USA	2794	China	3851
4	France	3504	China	3321	France	5574	China	2083	Spain	2662	USA	2705
5	China	2348	France	3174	China	4655	France	1980	France	1717	France	1729
6	Australia	2244	Australia	2069	Australia	3480	Australia	1372	Brazil	1470	Australia	1679
7	Germany	1508	Brazil	1776	Germany	2475	Portugal	953	Australia	1104	Brazil	1230
8	Portugal	1393	Germany	1434	Brazil	2259	Brazil	855	Germany	792	Portugal	1210
9	UK	1212	India	1072	Portugal	1939	Germany	829	Portugal	750	Germany	822
10	Brazil	1060	Portugal	1019	UK	1555	UK	580	Turkey	695	India	708
11	Canada	904	Turkey	972	Canada	1337	Canada	523	India	691	Turkey	707
12	South Africa	672	Japan	923	India	1333	South Africa	470	Iran	520	Chile	700
13	Greece	623	Canada	756	Japan	1286	Chile	444	Chile	519	Canada	697
14	New Zealand	613	Chile	689	Turkey	1139	New Zealand	420	Canada	445	UK	603
15	Chile	610	Iran	605	Chile	1055	Romania	416	South Africa	410	South Africa	539
16	Japan	591	Greece	602	South Africa	1010	Argentina	398	Japan	386	New Zealand	524
17	Argentina	523	South Africa	600	Greece	978	Greece	365	New Zealand	385	Romania	515
18	Romania	490	UK	530	New Zealand	879	India	363	South Korea	359	Greece	501
19	India	461	New Zealand	526	Argentina	739	Turkey	288	Greece	350	Argentina	488
20	Turkey	428	South Korea	478	South Korea	712	South Korea	280	Argentina	339	Iran	485

Table 3. World average number of citations per paper for the documents published in the 2016–2020 period, as extracted from the Wine-, Grape- and Wine + Grape-databases.

2016–2020	Number of documents	Number of citations	Citations per paper
Wine	10 620	68 079	6.4
Grape	11 226	72 872	6.5
Wine + Grape	17 420	109 559	6.3

Table 4. Number of documents and number of citations, and estimated citations per paper index for the top five nations in terms of number of papers published in the 2016–2020 period.

Rank	Country	Number of documents	Number of citations	Citations per paper
Grape-database				
1	China	1806	11 440	6.3
2	Italy	1594	13 842	8.7
3	USA	1313	10 021	7.6
4	Spain	1249	11 046	8.8
5	France	888	8357	9.4
Wine-database				
1	Spain	1586	13 584	8.6
2	Italy	1469	12 619	8.6
3	China	1255	8185	6.5
4	USA	1163	7770	6.7
5	France	1034	8200	7.9

their average values and SDs were, respectively, equal to 8.2 ± 1.2 and 7.7 ± 1.0. At the 95% confidence level, there was no statistically significant difference not only between such CPP values but also between them and the above world average CPP indexes for the W- (6.5) and G- (6.4) databases if their SD similarly ranged from 1.0 to 1.2.

Affiliations. The affiliation search returned a list of the institutions doing research in the wine and grape sector. Table S5 shows the number of papers published by the top 20 research centres/universities in terms of number of publications extracted from the W-, G- and W + G-databases over the 1950–2020 period. It is interesting to note how in the top positions there are universities distributed almost uniformly throughout the world, especially from Western Europe, California and Australia, these being among the main wine-producing areas.

Table 5, which analyses the papers published over the last 5 years (2016–2020), indicates the rise of some Chinese universities (i.e. Northwest A&F University and China Agricultural University).

Journals. Tables 6 and S6 report the top ten journals by number of publications retrieved from the W-, G- and W

Table 5. Number of publications per affiliation, extracted from the three Wine-, Grape- and Wine + Grape-databases in the 2016–2020 period.

	Wine		Grape		Wine + Grape	
Rank	Affiliation	Number of documents	Affiliation	Number of documents	Affiliation	Number of documents
1	Université de Bordeaux	254	Northwest A&F University	297	Université de Bordeaux	415
2	The University of Adelaide	247	Université de Bordeaux	273	Northwest A&F University	372
3	Northwest A&F University	188	Consiglio Nazionale delle Ricerche	255	Centre INRAE Bordeaux	325
4	Unité de Recherche Œnologie	181	University of California, Davis	241	Consejo Superior de Investigaciones Científicas	315
5	Consejo Superior de Investigaciones Científicas	178	Centre INRAE Bordeaux	237	The University of Adelaide	312
6	Centre INRAE -Bordeaux	173	Consejo Superior de Investigaciones Científicas	229	University of California, Davis	312
7	Universidad de La Rioja	169	Ministry of Agriculture of the People's Republic of China	226	Consiglio Nazionale delle Ricerche	298
8	University of California, Davis	160	China Agricultural University	218	China Agricultural University	283
9	Instituto de Ciencias de la Vid y del Vino	157	Instituto de Ciencias de la Vid y del Vino	194	Ministry of Agriculture of the People's Republic of China	260
10	Centre National de la Recherche Scientifique	151	Universidad de La Rioja	176	Universidad de La Rioja	252
11	Stellenbosch University	143	Empresa Brasileira de Pesquisa Agropecuária-Embrapa	175	Instiituto de Ciencias de la Vid y del Vino	245
12	Consejo Nacional de Investigaciones Científicas y Técnicas	135	The University of Adelaide	172	Centre National de la Recherche Scientifique	238
13	China Agricultural University	132	US Department of Agriculture-Agriculture Research Service, Washington	159	Universidade de Lisboa	214
14	Universidade de Lisboa	132	Istituto Agrario San Michele all'Adige	153	Unité de Recherche Œnologie	213
15	The Australian Wine Research Institute	128	Universidade de Lisboa	138	Stellenbosch University	203
16	Consiglio Nazionale delle Ricerche	127	Consejo Nacional de Investigaciones Cientificas y Técnicas	137	Consejo Nacional de Investigaciones Cientificas y Técnicas	190
17	University of Trás-os-Montes and Alto Douro	119	Centre National de la Recherche Scientifique.	132	Empresa Brasileira de Pesquisa Agropecuária-Embrapa	183
18	Université de Montpellier	117	INRAE's Occitanie-Montpellier Centre	129	INRAE's Occitanie-Montpellier Centre	181
19	Universitat Rovira i Virgili	115	Montpellier SupAgro	129	Istituto Agrario San Michele all'Adige	181
20	INRAE's Occitanie-Montpellier Centre	113	Università degli Studi di Torino	128	University of Trás-os-Montes and Alto Douro	178

INRAE, Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement.

+ G-databases over the 2016–2020 and 1950–2020 periods. Other indices of evaluation were included, namely: (i) the number of citations; (ii) the quartile (Q), which is a parameter derived from the normalisation of the Impact Factor (IF); (iii) the Scimago Journal Rank (SJR), an indicator introduced as an alternative to the IF, which measures the degree of influence of a scientific journal and is calculated both by counting the number of citations and assessing the prestige of the journal from which the citation comes; (iv) H-Index, still one of the most used bibliometric instruments to quantify the scientific impact of a journal based on the number of publications and citations received, despite criticism being raised for its use in this manner (Baccini 2010, Waltman and van Eck 2012); and (v) the average number of CPP.

Tables 6 and S6 also show the principal disciplinary sector of each journal selected for both the time periods selected. It can be noted that publication and citation behaviour change with the disciplinary sector; thus, a comparison among journals should be careful. During the long period (1950–2020), there was a prevalence of the agricultural and biological sciences, followed by food science and horticulture, as principal disciplines. In all the three W-, G- and W + G-databases, the *Journal of Agricultural and Food Chemistry* occupied first position for the highest number of citations (W + G: 107339; W: 84578; G: 59549), H-Index and CPP index. Other journals found to be relevant were *Food Chemistry* with the highest SJR value (1.78), and *Acta Horticulturae* with the lowest CPP value despite its position. Most fell within the first quartile (Q1) except for *Acta Horticulturae*

Table 6. Journals selected on the basis of the number of articles published, citations received, quartile position, Scimago Journal Rank, scientific impact, citations per paper, in the Wine-, Grape- and Wine + Grape-databases over the 2016–2020 period.

	Journal	Number of documents	Number of citations	Q	SJR	H-Index	CPP	Principal disciplinary sector
Wine								
1	Food Chemistry	458	6401	Q1	0.79	85	14.0	Food science
2	Food Research International	199	1731	Q1	1.44	149	8.7	Food science
3	Journal of Agricultural and Food Chemistry	188	1796	Q1	1.09	280	9.6	Agricultural and biological sciences
4	Molecules	167	1184	Q1	0.7	131	7.1	Pharmaceutical science
5	Oeno One	149	504	Q1	0.62	8	3.4	Horticulture
6	American Journal of Enology and Viticulture	145	778	Q1	0.79	85	5.4	Food science
7	Australian Journal of Grape and Wine Research	142	1079	Q1	0.94	72	7.6	Horticulture
8	International Journal of Wine Business Research	137	488	Q2	0.37	33	3.6	Business, management and accounting
9	Journal of the Science of Food and Agriculture	126	1048	Q1	0.72	131	8.3	Agronomy and crop science
10	European Food Research and Technology	125	716	Q1	0.65	95	5.7	Industrial and manufacturing engineering
Grape								
1	Acta Horticulturae	410	405	Q4	0.18	54	1.0	Horticulture
2	Food Chemistry	282	4719	Q1	0.79	85	16.7	Food science
3	Scientia Horticulturae	221	1553	Q1	0.84	102	7.0	Horticulture
4	Frontiers in Plant Science	216	2988	Q1	1.69	101	13.8	Plant science
5	Australian Journal of Grape and Wine	171	1252	Q1	0.94	72	7.3	Horticulture
6	American Journal of Enology and Viticulture	164	986	Q1	0.94	72	6.0	Horticulture
7	Journal of the Science of Food and Agriculture	152	1321	Q1	0.72	131	8.7	Agronomy and crop science
8	Oeno One	149	647	Q1	0.62	8	4.3	Horticulture
9	Plant Disease	143	796	Q1	0.68	102	5.6	Agronomy and crop science
10	Journal of Agricultural and Food Chemistry	138	1374	Q1	0.68	280	10.0	Agronomy and crop science
Wine + Grape								
1	Food Chemistry	570	8714	Q1	0.79	85	15.3	Food science
2	Acta Horticulturae	422	410	Q4	0.18	54	1.0	Horticulture
3	Journal of Agricultural and Food Chemistry	244	2340	Q1	0.68	280	9.6	Agronomy and crop science
4	Australian Journal of Grape and Wine Research	230	1631	Q1	0.94	72	7.1	Horticulture
5	Scientia Horticulturae	229	1595	Q1	0.84	102	7.0	Horticulture
6	Food Research International	228	2071	Q1	1.44	149	9.1	Food science
7	American Journal of Enology and Viticulture	222	1266	Q1	0.94	72	5.7	Horticulture
8	Molecules	219	1733	Q1	0.7	131	7.9	Pharmaceutical science
9	Frontiers in Plant Science	217	2988	Q1	1.69	101	13.8	Plant science
10	Oeno One	196	758	Q1	0.62	8	3.9	Horticulture

CPP, citations per paper; H-Index, scientific impact of a journal based on the numbers of publications and citations received; Q, quartile position; SJR, Scimago Journal Rank.

(Q4), and the *Journal of Food Science* and the *Journal of Wine Research*, both belonging to the second quartile (Q2). Over the latest 5 years (2016–2020), the most prominent journal in the W- and W + G-databases was *Food Chemistry* with the highest number of citations across all databases and higher CPP index. For the wine sector, in addition to the journals mentioned above, other new journals, that is *Molecules*, *Oeno One* and *International Journal of Wine Business Research*, entered in the top ten journal list (Table 6). *Food Research International* occupied the ninth place (Table S6), but over the last 5 years gained second position (Table 6). *Acta Horticulturae* disappeared from the top ten list in the wine sector, but it gained the first place in the grape sector for the highest number of publications. In such a sector, the *Journal of Agricultural and Food Chemistry* fell from second (Table S6) to tenth place (Table 6), indicating that over the last 5 years the journal published fewer articles in this area, even though it maintained the highest H-Index value (280).

Authors. Table S7 shows a ranking of the most published authors extracted from the W-, G- and W + G-databases, as well as the overall number of citations, and number of CPP over the 1950–2020 period.

In the W-database, there was a prevalence of authors working in European institutions, especially in France and Spain, namely Vicente Ferreira (Spain), who produced the highest number of articles (175); Denis Dubourdieu (France), who obtained the highest number of citations (8996); and Véronique Cheynier (France), who received the highest CPP index (90.7).

By analysing the G-database, the most published authors differed from those working in the wine sector, except for Luca Rolle and Teresa Garde-Cerdán. Both these authors were of European origin, apart from Andrew Walker (USA) in the second position for the number of articles published (118). The ninth and tenth positions were occupied by authors working in Chinese institutions, that is Yuejin Wang and Jinggui Fang. As compared to the W-database, there was a greater Italian activity in the grape research sector; Osvaldo Failla, Stefano Poni and Luca Rolle being at the first, third and fourth position for the number of articles published, respectively (Table S7). It is also worth noting that the French author, Patrice This, received the highest number of citations (5412) and CPP index (55.8). In the W + G-database, there was correspondence among top published authors in the wine and grape sector, the most published authors being researchers in Spanish, French and Italian institutions.

Table 7 shows the top publishing authors during the latest 5 years. In the wine sector a few authors did not appear in the top ten list of the 1950–2020 period, namely the Australian researcher David Jeffery, who reached the second position with 49 papers, and the Chinese author Changqing Duan, who gained the fifth position. The most published author with 52 articles was Teresa Garde-Cerdán (Spain), while Vicente Ferreira (Spain), being also listed in Table S7, obtained the highest CPP index (12.6). The G-database, in the 2016–2020 period, showed a greater presence of Chinese authors. Fang Jinggui authored the highest number of articles (61), being followed by Wang Yuejin

Table 7. Authors ranked by the number of articles published, together with the country of origin, number of citations and citations per paper index in the 2016–2020 period.

	Author	Country	Number of documents	Number of citations	Citations per paper
Wine					
1	Garde-Cerdán, T.	Spain	52	556	10.7
2	Jeffery, D.W.	Australia	49	506	10.3
3	Ferreira, V.	Spain	48	604	12.6
4	Rolle, L.	Italy	48	517	10.8
5	Duan, C.Q.	China	41	364	8.9
6	Teissedre, P.L.	France	41	360	8.8
7	Morata,	Spain	40	436	10.9
8	Giacosa, S.	Spain	38	380	10.0
9	Anderson, K.	Australia	37	41	1.1
10	Bastian, S.E.P.	Australia	36	313	8.7
Grape					
1	Fang, J.	China	61	408	6.7
2	Garde-Cerdán, T.	Spain	59	634	10.7
3	Rolle, L.	Italy	49	523	10.7
4	Wang, Y.	China	45	458	10.2
5	Poni, S.	Italy	43	429	10.0
6	Giacosa, S.	Italy	42	391	9.3
7	Gutiérrez-Gamboa, G.	Spain	41	365	8.9
8	Ollat, N.	France	41	380	9.3
9	Wang, X.	China	41	481	11.7
10	Zhai, H.	China	40	157	3.9
Wine + Grape					
1	Garde-Cerdán, T.	Spain	70	750	10.7
2	Fang, J.	China	61	408	6.7
3	Rolle, L.	Italy	58	572	9.9
4	Duan, C.Q.	China	57	543	9.5
5	Jeffery, D.W.	Australia	51	521	10.2
6	Ferreira, V.	Spain	49	616	12.6
7	Giacosa, S.	Italy	47	426	9.1
8	Teissedre, P.L.	France	47	497	10.6
9	Ollat, N.	France	45	423	9.4
10	Wang, Y.	China	45	458	10.2

Table 8. Textual analysis of the abstracts extracted from the Wine-database reporting the main types of products, generic research terms, analytical compounds and grape cultivars with their relative occurrence for the most publishing countries.

	USA	No.	Spain	No.	Italy	No.	France	No.	China	No.
Products										
1	red wine	192	red wine	201	red wine	162	red wine	165	red wine	311
2	white wine	42	sparkling	128	sparkling	110	champagne	121	white wine	57
3	champagne	34	grape marc	76	white wine	82	sparkling	55	brandy	45
4	sparkling	33	white wine	45	vinegar	37	white wine	45	grappa	18
5	grappa	31	vinegar	34	grape marc	34	grape marc	31	vinegar	17
6	grape marc	20	brandy	10	grappa	24	brandy	10	icewine	15
7	vinegar	13	champagne	6	passito	19	vinegar	9	grape marc	5
8	brandy	10	orujo	5	malvasia	15	grappa	3	zinfandel	4
9	chenin blanc	3	malvasia	5	brandy	8	chenin blanc	3	orange wine	4
10	zinfandel	2	amphora	5	lambrusco	7	botrytised wines	2	rose wine	3
Research terms										
1	consumption	207	composition	560	composition	365	composition	280	expression	341
2	composition	183	addition	283	consumption	245	addition	171	addition	316
3	addition	142	extraction	274	addition	204	consumption	158	detection	235
4	extraction	121	consumption	232	extraction	166	extraction	104	extraction	232
5	expression	90	detection	119	detection	86	adaptation	79	composition	188
6	detection	88	determination	87	expression	85	detection	71	determination	110
7	supplementation	48	expression	80	accumulation	82	expression	64	consumption	108
8	accumulation	46	classification	73	identification	80	quantification	57	accumulation	103
9	classification	41	accumulation	68	classification	76	identification	47	classification	83
10	adsorption	35	identification	62	innovation	68	accumulation	42	supplementation	59
Analytical compounds										
1	tannins	92	antioxidant	228	antioxidant	230	tannins	173	antioxidant	343
2	anthocyanins	91	anthocyanins	210	polyphenols	188	polyphenols	100	anthocyanins	300
3	polyphenols	75	polyphenols	200	anthocyanins	180	anthocyanins	93	esters	233
4	antioxidant	69	tannins	157	tannins	161	sugar	82	sugar	175
5	sugar	60	acidity	155	sugar	135	antioxidant	78	polyphenols	136
6	acidity	44	esters	129	acidity	121	esters	59	proanthocyanidins	109
7	proanthocyanidins	39	malolactic	94	esters	92	acidity	40	tannins	85
8	resveratrol	23	sugar	83	resveratrol	64	sensory characteristics	30	flavonoids	75
9	flavonoids	20	lactic acid	82	proanthocyanidins	56	proanthocyanidins	29	resveratrol	65
10	glycerol	19	glycerol	73	flavonoids	55	resveratrol	27	acetic acid	60
Grape cultivars										
1	sauvignon	88	tempranillo	154	sangiovese	118	sauvignon	73	sauvignon	210
2	pinot	69	rioja	84	chardonnay	66	chardonnay	62	merlot	47
3	chardonnay	53	sauvignon	75	sauvignon	60	pinot	37	chardonnay	28
4	merlot	40	syrah	46	pinot	49	sangiovese	31	riesling	21
5	syrah	33	chardonnay	38	nebbiolo	42	merlot	28	pinot	20
6	sangiovese	16	sauvignon blanc	30	merlot	40	sauvignon blanc	28	syrah	14
7	shiraz	15	carignan	26	barbera	36	tempranillo	20	marselan	14
8	cabernet franc	13	grenache	25	syrah	27	syrah	12	cabernet franc	10
9	tempranillo	10	pinot	20	trebbiano	13	rioja	12	red globe	8
10	riesling	8	riesling	17	rioja	9	grenache	6	shiraz	7

Table 9. Textual analysis of abstracts extracted from the Grape-database reporting the main types of analytical compounds, generic research terms, cultivar and disease with relative occurrence also divided by countries.

	USA	No.	Spain	No.	Italy	No.	France	No.	China	No.
Analytical compounds										
1	Anthocyanins	141	Antioxidant	262	Antioxidant	281	Sugar	142	Anthocyanins	374
2	Antioxidant	128	Anthocyanins	229	Anthocyanins	269	Tannins	110	Antioxidant	371
3	DNA	99	Polyphenols	180	Polyphenols	222	Anthocyanins	101	Sugar	273
4	Polyphenols	92	Acidity	131	Sugar	182	Polyphenols	81	Resveratrol	120
5	Sugar	83	Sugar	104	Acidity	146	Stilbenes	72	Polyphenols	116
6	Acidity	69	Tannins	94	Tannins	105	Antioxidant	69	Proanthocyanidins	106
7	Tannins	62	Stilbenes	82	Flavonoids	87	Resveratrol	61	Esters	101
8	RNA	61	Flavanols	63	DNA	83	Acidity	44	Flavonoids	101
9	Resveratrol	59	Proanthocyanidins	60	Proanthocyanidins	69	DNA	26	DNA	81
10	Proanthocyanidins	44	Resveratrol	53	Microbiota	66	Proanthocyanidins	24	RNA	77
Research terms										
1	Expression	294	Composition	533	Composition	412	Composition	273	Expression	1247
2	Composition	236	Addition	232	Expression	267	Expression	195	Accumulation	445
3	Addition	165	Extraction	229	Accumulation	230	Accumulation	129	Addition	364
4	Accumulation	144	Expression	160	Addition	216	Addition	129	Detection	199
5	Detection	105	Accumulation	112	Extraction	216	Extraction	106	Composition	183
6	Incidence	84	Detection	80	Identification	119	Adaptation	76	Extraction	173
7	Extraction	81	Identification	73	Detection	88	Identification	57	Inhibition	86
8	Consumption	66	Classification	62	Consumption	83	Consumption	49	Identification	85
9	Efficacy	66	Determination	59	Efficacy	62	Detection	39	Consumption	78
10	Identification	66	Consumption	58	Incidence	61	Classification	32	Determination	72
Grape cultivars										
1	Sauvignon	137	Tempranillo	250	Sangiovese	139	Sauvignon	103	Sauvignon	289
2	Cabernet Sauvignon	126	Sauvignon	87	Pinot	114	Chardonnay	74	Cabernet Sauvignon	273
3	Pinot	119	Syrah	61	Sauvignon	103	Cabernet Sauvignon	65	Red Globe	122
4	Pinot Noir	94	Cabernet Sauvignon	54	Pinot Noir	74	Merlot	57	Pinot	64
5	Chardonnay	74	Chardonnay	54	Chardonnay	73	Pinot	47	Merlot	60
6	Merlot	67	Pinot	44	Nebbiolo	70	Pinot Noir	38	Chardonnay	52
7	Syrah	46	Grenache	43	Cabernet Sauvignon	68	Syrah	37	Pinot Noir	50
8	Cabernet Franc	27	Rioja	40	Barbera	64	Tempranillo	35	Riesling	19
9	Pinot Gris	19	Sauvignon Blanc	29	Merlot	52	Sauvignon Blanc	26	Syrah	18
10	Sangiovese	18	Pinot Noir	22	Sauvignon Blanc	32	Sangiovese	23	Marselan	18
Diseases										
1	Red Blotch	64	Botrytis	29	Phytoplasma	90	Botrytis	46	Botrytis	59
2	Leafroll	57	*Botrytis cinerea*	14	Botrytis	66	Phytoplasma	41	*Botrytis cinerea*	50
3	Botrytis	36	Leafroll	7	*Botrytis cinerea*	51	*Botrytis cinerea*	30	Anthracnose	32
4	Phytoplasma	27	Grapevine fanleaf	6	Bois noir	32	Grapevine fanleaf	19	*Alternaria*	29
5	*Botrytis cinerea*	24	Fleck	5	Flavescence doreè	25	Flavescence dore	15	MLO (Mycoplasma-like organism)	10
6	Grapevine fanleaf	11	Yellow speckle	4	*Candidatus phytoplasma*	18	Bois noir	10	*Aspergillus niger*	9
7	Grapevine yellows	10	Phytoplasma	3	Leafroll	18	Leafroll	9	Grapevine fanleaf	7
8	*Alternaria*	9	*Alternaria*	2	Grapevine yellows	13	*Xiphinema*	8	Yellow speckle	6
9	Fleck	7	*Lasiodiplodia theobromae*	2	Grapevine fanleaf	11	*Candidatus phytoplasma*	7	*Lasiodiplodia theobromae*	5
10	Yellow speckle	7	*Xiphinema*	2	Fleck	8	*Xiphinema index*	6	*Alternaria alternata*	4

(45), Xiping Wang (41), and H. Zhai (40). As already deducted from the previous analyses, this confirmed the growing Chinese interest towards viticulture research.

The greatest number of citations was obtained by Teresa Garde-Cerdán (634), while Xiping Wang received the highest CPP index (11.7). In general, in all three databases, six, three or one of the top ten published authors were of European, Chinese or Australian origin, respectively. Compared to the 1950–2020 period, no US author was present in the list shown in Table 7.

Textual analysis

W-database. Table 8 shows the occurrence of selected terms (see also Table S2), these being extracted from the W-database for the main wine producing countries: USA, Spain, Italy, France and China. The number of frequencies was obviously an expression of how many times each term was found in the abstracts of the papers included in such a database, depending also on the number of publications indexed. For this reason, the values obtained give an indication within the category considered (countries), but they cannot be used for comparison among other categories. The product 'red wine' dominated in all of them and especially in China, where it exhibited a high frequency (311) as compared to the other terms. The terms 'white wine' and 'sparkling wine' were highly recurrent in France, Italy and the USA. As an example, in France the term 'champagne' reached almost the same frequency of the term 'red wine'. In China, the term 'brandy' was also frequently cited as the term 'grape marc' was in Spain.

By analysing general search terms, it was possible to point out a certain differentiation among these countries. In the European papers from Spain, Italy and France, the terms 'composition' and 'consumption' were the most frequently used, the latter being also the most frequent in the USA (207). In contrast, the most used terms in the Chinese papers were 'expression' (341), 'addition' (316) and 'detection' (235). By analysing the main 'analytical' terms used in the wine sector, the word 'antioxidant' prevailed in China (343), although it was important in all the other countries examined. Other important terms were 'anthocyanins', 'polyphenols' and 'anthocyanidin', just to emphasise that the main research topics aimed at evaluating the antioxidant content (and sensory properties) of wine, but probably also the health aspects ('resveratrol'), as shown in Table 8. The grape cultivars of interest were related to the country of origin; Sangiovese being the cultivar most used in Italy, Tempranillo in Spain and Sauvignon in France, even if the latter was the cultivar most cited in the USA and China. In particular, the term Sauvignon included every occurrence for Sauvignon, such as Sauvignon Blanc, and Cabernet Sauvignon, to avoid the double counting from the Phyton script.

G-database. By referring to the G-database, Table 9 shows the first ten products in the most publishing countries for the grape research sector. The chemical compound most frequently mentioned was 'antioxidant' in Italy and Spain,

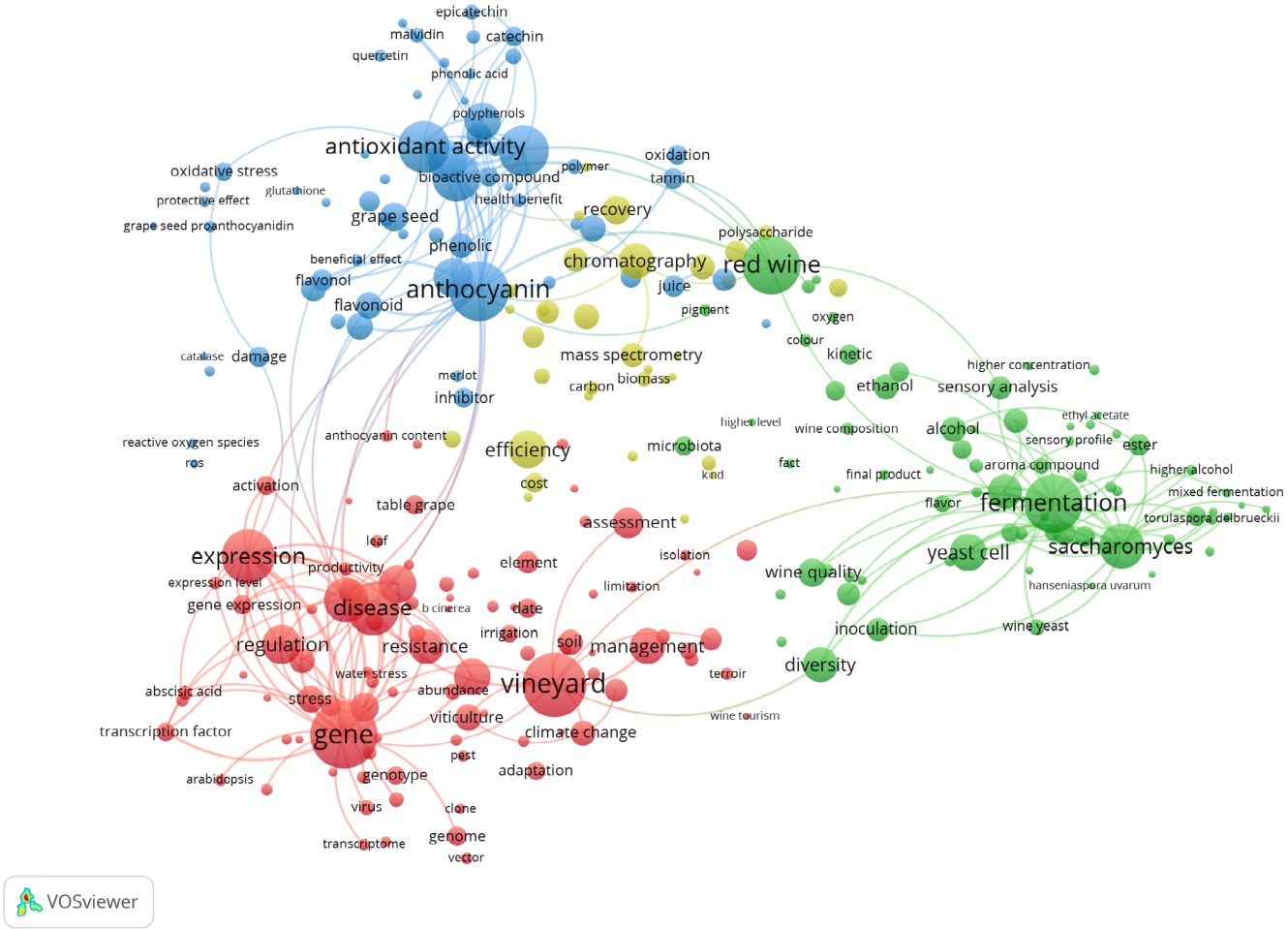
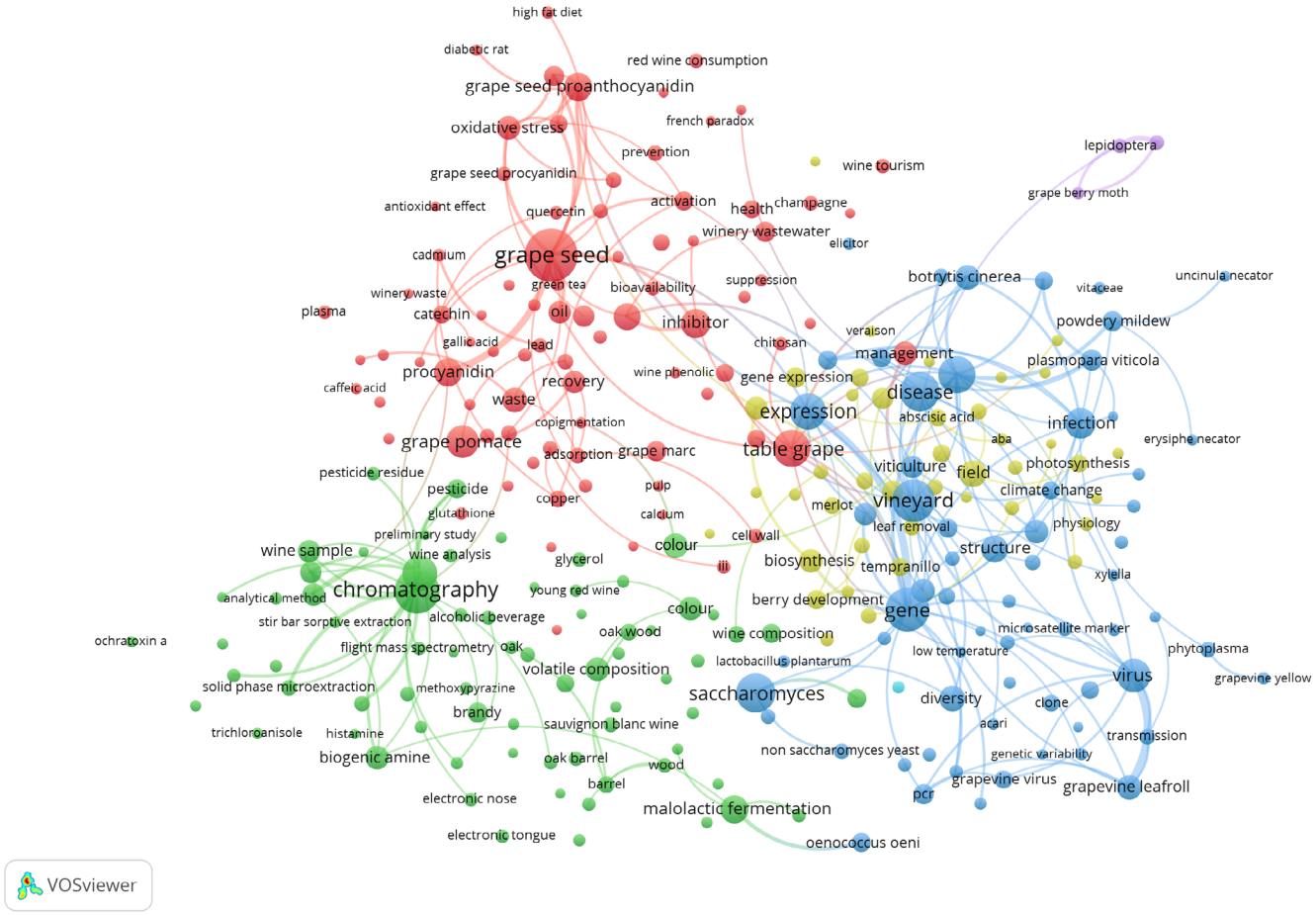
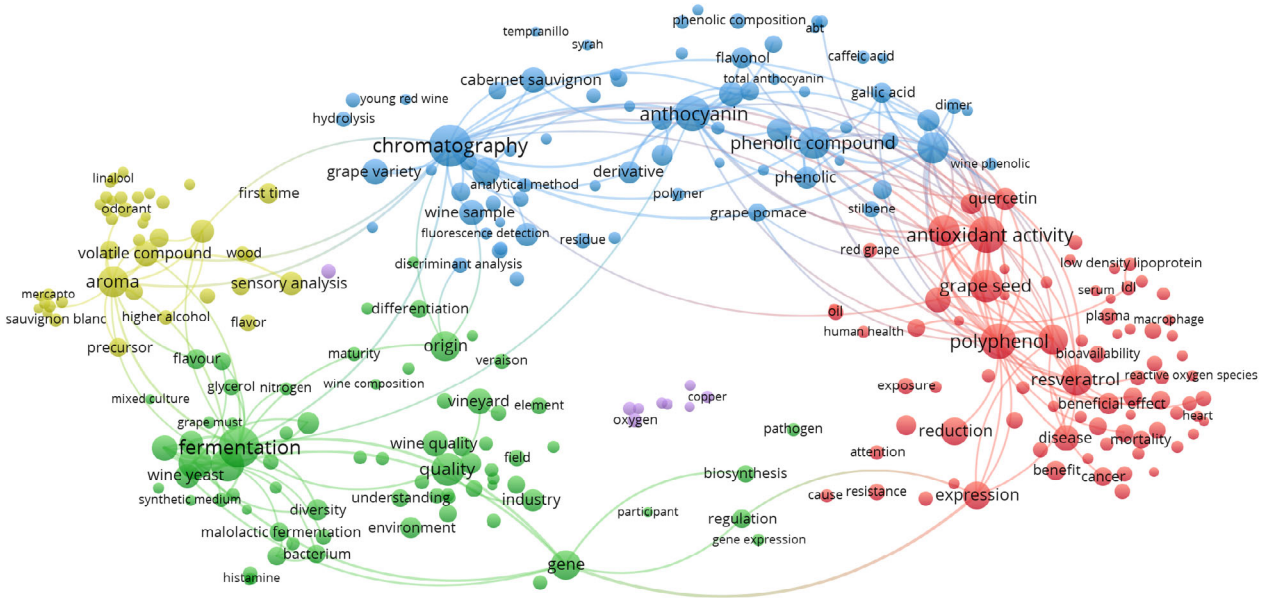


Figure 3. The terms map (abstracts and titles) of the 2000 most cited papers in the Wine + Grape-database in the 2016–2020 period.



VOSviewer

Figure 4. The terms map (abstracts and titles) of the 2000 most cited papers in the Wine + Grape-database in the 1950–2020 period.



VOSviewer

Figure 5. The terms map (abstracts and titles) of the 2000 most cited papers in the Wine-database in the 1950–2020 period.

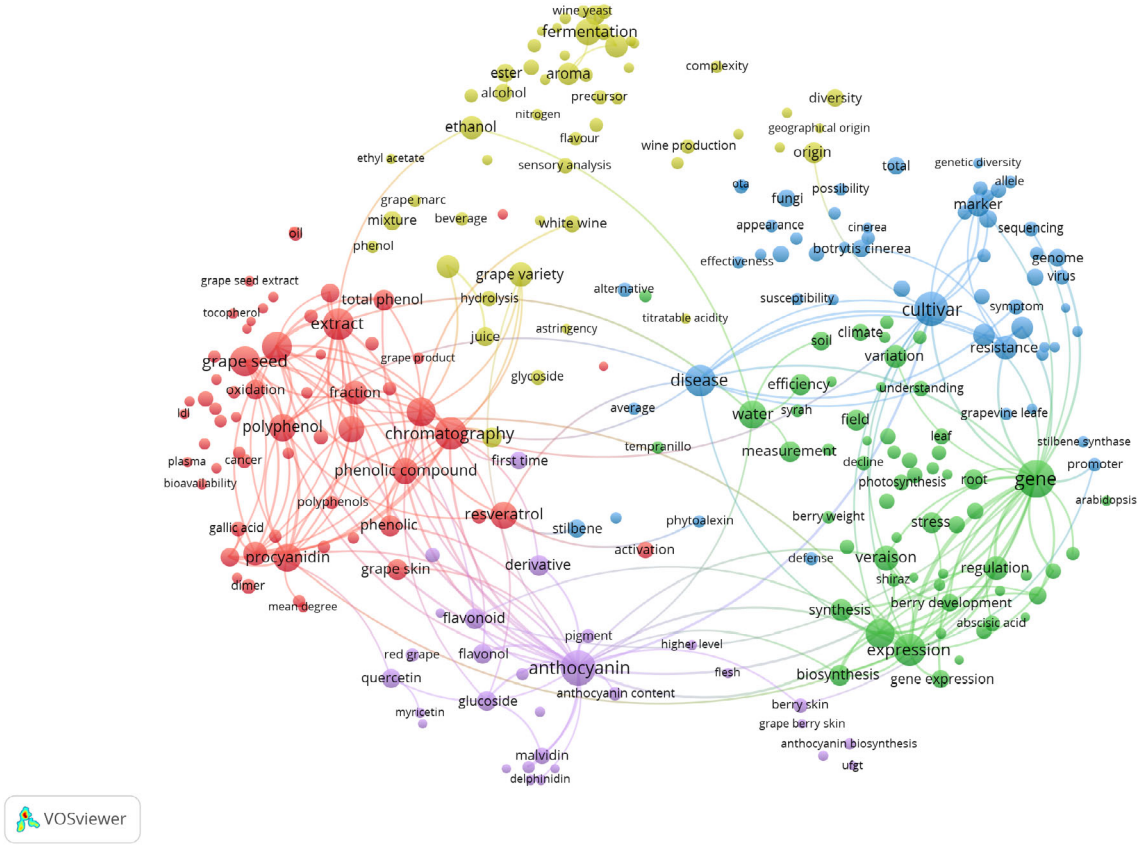


Figure 6. The terms map (abstracts and titles) of the 2000 most cited papers in the Grape-database in the 1950–2020 period.

'anthocyanins' in the USA and China and 'sugar' in France. In all these countries, the compounds most studied were the antioxidants. By analysing the grape cultivars, Pinot, Merlot and Chardonnay were most cited, while Red Globe was highly cited in Chinese papers, such a cultivar being at third place. As concerning the relative frequency for the main grape diseases, *Botrytis* was widely studied in Italy, Spain and China, although in Italy the prevalent disease was phytoplasma (90) and in the USA red blotch and leafroll. Among the generic terms, the terms 'composition' and 'expression' were largely used, especially in Spain (533) and China (1247), respectively, as well as 'accumulation' and 'addition'.

Map analysis

By using the software VOSviewer, Figure 3 shows the bibliometric map of co-occurrence for the terms extracted from the abstracts and titles of the 2000 most cited papers from 2016 to 2020 (included), as collected from the W + G-database.

The map shows the presence of four main clusters identified by the different colours. The green cluster shows terms related to fermentation studies, where the terms 'fermentation' and 'red wine' were those mostly used, these being shown by the large diameter of their spots. In this cluster, it is worth noting the presence of terms, such as 'yeast cell', '*Saccharomyces*', 'sensory analysis', 'flavour', 'alcohol', 'ethanol', 'wine quality', 'inoculation', 'mixed fermentation' and 'diversity'. In the red cluster, the term 'gene' was most quoted. Other main terms of this cluster were 'expression', 'disease', 'regulation', 'vineyard', 'resistance', 'genotype', 'stress' and 'viticulture'. Clearly, the cluster referred to the viticulture sector, where vine genetics is of fundamental importance in the response to abiotic and non-abiotic stress factors. Moreover, the term 'vineyard' was close to 'climate change' to highlight the close correlation between global warming and the effects on vine and viticulture in general. The blue cluster identified the terms related to the chemical analytical field, mainly focused on the detection of the 'antioxidant activity' in the wine matrix and raw materials (i.e. 'grape seed'), as 'anthocyanin', 'flavonoid', 'phenolic' and 'polyphenols', for its positive effects on health, 'bioactive compounds' and 'health benefit'. The fourth and yellow cluster shared with the blue cluster and included terms, such as 'chromatography' and 'mass spectrometry', which were related to 'tannin' and 'anthocyanin', while the term 'polysaccharide' was linked to the green cluster, especially with the term 'red wine'. Altogether, these terms highlighted the analytical techniques mostly used.

Figure 4 shows the map derived from the terms used in the 2000 articles mostly cited during the overall 1950–2020 period, as retrieved from the W + G-database. The cluster identified with the blue colour was characterised by the term 'gene' together with other terms, such as 'vineyard', 'expression', 'disease', '*Saccharomyces*' and '*Botrytis cinerea*', 'climate change', 'infection' and 'virus'. It represents the main topics of viticulture. The term 'grape seed' predominated in the red cluster, in which other terms, such as 'oil', 'quercetin', 'grape pomace', 'procyanidin', 'grape seed', 'proanthocyanidin', 'inhibitor' and 'table grape', were found. Generally, such terms correlated with those of the blue and yellow clusters and identified both the sensory properties of wine and the human health research topic. Finally, the green cluster showed a predominance for the

analytical field. In fact, the most cited word was 'chromatography', this one having had a low citation frequency in the most recent 2016–2020 period. Other terms used were the following: 'wine analysis', 'wine sample', 'analytical method', 'biogenic amine', 'solid phase microextraction', 'composition' and 'volatile composition', as well as 'electronic nose' and 'electronic tongue'.

Figure 5 displays the map obtained by analysing the first 2000 most cited articles of the W-database in the 1950–2020 period. It allows the identification of four main clusters. Also in this case, 'grape seed' was the prevailing term and belonged to the red cluster. It was followed by 'antioxidant activity', 'polyphenols', 'resveratrol' and some other terms related to human health such as 'cancer', 'mortality', 'heart' and 'low-density lipoprotein'. The blue cluster was characterised by 'chromatography' as a relevant word, even if other terms, such as 'anthocyanin', 'phenolic compound' and 'grape variety', were identified. This cluster was also connected to the yellow cluster, that was represented by 'aroma', 'sensory analysis' and 'precursor'. In the green cluster the word most mentioned was 'fermentation', this being followed by 'gene', 'quality' and 'origin'.

Figure 6 shows the map obtained from the analysis of the first 2000 most cited papers retrieved from the G-database for the 1950–2020 period. In this case, five clusters were identified. In the green cluster, the most relevant term was 'gene', followed by 'expression', 'stress', 'regulation' and 'veraison' (the onset of the ripening of grapes). In the blue cluster the relevant terms 'cultivar' and 'disease' were noted. In particular, the latter was in the central area of the map and was related to the green and red clusters. The yellow cluster pointed out the compounds related to 'fermentation' and grape cultivar, such as 'origin', 'aroma', 'ethanol' and 'complexity'. The light violet cluster included not only the term 'anthocyanin', which was related to the terms in the green ('expression') and red ('grape skin', 'procyanidin' and 'resveratrol') clusters, but also other terms, such as 'flavonoid', 'pigment' and 'quercetin'.

Summary of results and conclusions

The present bibliometric review highlighted the presence of some novel aspects regarding the actual wine and viticulture research sectors. The historical interest towards the scientific research in the field of oenology and viticulture was highlighted; the number of publications produced by both research sectors being relevant, but similar. The number of papers published per year during the 1970–1990 period was relatively low (84 ± 31, 64 ± 27 and 135 ± 51 for the W-, G-, and W + G-databases, respectively), but they grew up to 2000–2500 per year in 2020. Thus, the two sectors have almost had the same evolution in terms of number of publications, and therefore they aroused similar scientific interest, essentially in a restricted number of countries, namely Spain, Italy, France, the USA, China, Brazil and South Africa. Despite such countries representing practically all continents, there was a prevalence of European countries. In the most recent years, there has been a clear reduction in interest in both sectors by US authors. In fact, from 2016 to 2020 they have produced only 33% of the overall publications published since 1950, unlike China (83%), Spain (52%) and Italy (59%).

Over the last 10 years in the G- and W + G-databases, Italy was the nation that produced the greatest number of publications; their overall number of citations being also higher in the 2016–2020 period. In contrast, in the field of oenology Italy was just behind Spain for both indicators. During such a time period, the Université de Bordeaux and INRAE's Occitanie—Montpellier Centre in France were the most active research centres in the field of oenology. Actually, four French research centres were in the top ten list; this including also Chinese and Spanish research centres. In the field of viticulture, the Chinese, French and Italian research centres prevailed. In France there are a few research centres, highly specialised in this field, that practically produced the largest number of publications in recent years, while in Italy, the USA and China there are a greater number of research centres that have published a lower number of peer-reviewed articles.

Over the last 5 years, even the scientific journals exhibited inverted trends. For the wine sector, the papers moved from the *Journal of Agriculture and Food Chemistry*, its disciplinary field mainly regarding the agriculture and biological sciences, to *Food Chemistry*, this might be pointing towards a switch of the scientific interest from agronomy to chemistry. This was observed as well in the field of viticulture. In fact, *Acta Horticulturae* was still in the first place in terms of number of publications, but *Food Chemistry* reached the first place for number of citations and CPP index.

From the text analysis of abstracts (Table 8), it was evident that 'red wine' was the main product studied, followed by 'white wine' in the USA and China, and 'sparkling wines' ('champagne' and 'spumante') in Spain, Italy and France. Moreover, in China there was a clear scientific interest for spirits, such as 'brandy' and 'grappa', whereas in the USA for 'sparkling wines'. The grape cultivars of interest strictly depended on the country of origin, while the main chemical compounds analysed were those related to the antioxidant properties of wine and grape matrices. These results were practically in line with those observed by Aleixandre-Tudo et al. (2019). In fact, these authors confirmed the significant role played by phenolic compounds in wine sensory properties and foresaw further research efforts for a full comprehension of the astringency and bitterness phenomena; the current comprehension of the phenolic chemistry and its role played on wine quality being still retained inconclusive.

The map analysis identified that in the latest years the scientific research has been still focused on the antioxidant components present in such matrices, mainly grape seeds, with a large interest in anthocyanins and a series of polyphenols, such as epicatechins, catechins, malvidin and quercetin.

The analysis of the map extracted from the first 2000 most cited articles for the W + G-database from 1950 to 2020 showed three main clusters (Figure 4). In the blue cluster the most relevant agronomic aspect was related to the control of vineyard diseases/infections by viruses, fungi and bacteria. The interest in genetics and in gene expression of the vine is an important field of study. The red cluster revealed a relationship among terms related to the recovery/reuse of healthy compounds, such as proanthocyanin and procyanidin, contained in the seeds and skins of berries, even if their role in the mouthfeel and colour properties of wines was not pointed out. The green cluster included all the terms directly connected to the chemical analysis of the wine and grape compounds with particular attention to the aromatic components involved in wine ageing in wood casks. Over the last 5 years, the map in Figure 3 still pointed out three main clusters. The red cluster related to viticulture presented innovative aspects when compared to previous

years, as there was a link between climate change and adaptation of vineyards in terms of abiotic factors, such as soil and irrigation, and of biotic factors, and resistance to diseases and the effect of vine gene expression to these diseases. The green-coloured cluster highlighted the study of the fermentation process and sensory profile/aroma of wine. In particular, the inoculation of *Saccharomyces cerevisiae* and other non-*Saccharomyces* yeasts was highlighted. The application of non-*Saccharomyces* yeasts for wine improvement and diversification has gained considerable relevance in recent years in mixed fermentation (Fresno et al. 2017). Such yeasts are predominant on grapes and in musts during the pre-fermentation phase. There is, in fact, considerable oenological interest in yeasts belonging to the genus *Torulaspora* (i.e. *Torulaspora delbrueckii*) for their qualitative contribution to wine quality and complexity, clean fermentation and varietal aromatic development with low production of volatile acidity, acetaldehyde, diacetyl and acetoin (Belda et al. 2015), or in *Hanseniaspora*, such as *Hanseniaspora uvarum*, this being the only apiculate yeast isolated in spontaneous fermentations yielding a higher concentration of alcohols, esters, fatty acids and heavy sulfur compounds in red wines (Moreira et al. 2011).

It is also important to comment not only what was present in the map, but also the absence of certain research topics. For example, it was evident from Figure 3 that the most cited papers were mainly focused on the healthy/antioxidant characteristics of the compounds present in wine. It is thus worth noting that this bibliometric analysis carried out using the Scopus database neither pointed out the crucial role of phenolics on the mouthfeel properties of the wines nor the negative implications of the consumption of an alcoholic beverage, such as wine, on the human health. Further searches on the Scopus database allowed the retrieval of as much as 1280 or 1011 documents dealing with the antioxidant/health effects or mouthfeel properties of polyphenols in wine, showing quite a similar importance for both topics. Only in Figure 3 the term 'alcohol' was associated with the term 'fermentation'. Thus, from the map analysis shown in Figure 3 the effect of wine consumption on human health was neither positively nor negatively accounted for. Moreover, there was no indication on the benefit of moderate wine consumption. Obviously, this does not necessarily mean the absence of papers on such topics. In fact, the lack of certain terms in the clusters generated by VOSviewer might be because of its default setting. In this work, only terms occurring at least 50 times were selected to make the map readable and exclude terms unconnected in the network. Thus, the high per capita consumption of wine in some European countries, such as Portugal, Luxembourg, France and Italy with 62.1, 55.5, 50.2 and 43.7 L/year, respectively (Mercer 2021), as well as the high ethanol concentration of wine, has attracted practically no scientific interest over the last 5 years. In contrast, for another alcoholic beverage, such as beer with an alcoholic concentration (4.8% v/v) much lower than that of wine (11% v/v) (https://www.statista.com/statistics/269735/alcohol-content-of-a-glass-of-beer-wine-champagne-and-spirits), the effect of the alcohol consumption on human health was so much more widely discussed to represent a social objective of communication for beer producers (Pallottino et al. 2020), as well as a market target for low-alcohol or alcohol-free alternatives. Even if this aspect was not pointed out by the textual analysis of the papers retrieved from the Scopus database, the search engine Google revealed that there is ongoing research to obtain alcohol-free counterparts of wine against neurodegenerative diseases, as well as non-alcoholic beverages rich in antioxidants extracted from grapes active against degenerative Alzheimer's and Parkinson's diseases. Moreover, even if the European Commission proposal to amend regulation number 1308/2013 (European Parliament 2013), and introduce the terms 'dealcoholised wine' and 'partially dealcoholised wine' with an alcohol concentration ≤0.5% (v/v) or between 0.5 and 9% (v/v), respectively, has not been approved yet, several Italian and Portuguese wine associations appear to be in favour of introducing alcohol-free wines so as to attract new consumers (https://valentepali.com/en/alcohol-free-wine-yes-no/). In our opinion, there is an excessive scientific emphasis on the presence of potentially healthy compounds in wine (or in its by-products or waste products) which distracts the attention of the consumer from the real danger of alcohol consumption, especially among young people. At low doses alcohol consumption may exert beneficial effects to some population groups in relation to cardiovascular disease and diabetes mellitus (Pavlidou et al. 2018, Minzer et al. 2020, Teissedre et al. 2020). There is, however, a positive dose–response relationship between any alcohol consumption and cancer at certain sites, with no apparent lower threshold (Kunzmann et al. 2018).

Another important aspect (which also differentiates wine from beer research) was the absence of terms (or clusters) related to the fermentation technology. In all probability, the current scientific research in the oenology field retains wine technology as mature and already optimised. Despite the new prospects expected by the upcoming digital transformation and robotic operations of the food and beverage industry (FoodDrinkEurope 2020), the margins of improvement appear to be minimal with respect to resources needed for further optimisation. In fact, over 77% of Italian wineries have not invested or have invested only up to €5000 in information and communication technologies in the last 5 years (Capeccioni 2020). Most of the digital investments made so far have been aimed at expanding the company's customer base by improving the distribution phase of the supply chain and allowing direct sales to the public in 41 and 43% of cases, respectively (Capeccioni 2020). Therefore, except for the genetic work on the microbial side, the current wine research appears to be simply explorative. Based on a set of well-codified analytical techniques, most of the studies directed to recover phenolics from grape seeds and skins for their potential nutritional valorisation just tends to verify the technical feasibility of the process at a laboratory scale with no cost/benefit or market analysis. In contrast, the scientific activity related to viticulture appears to be more open and livelier. Its innovative thrust was evident, mainly given by the evolution of the techniques of genetic analysis and improvement of the vine in response mainly to abiotic stress factors, such as global warming and water stress, and biotic stress factors, such as diseases and viruses, as well as the reuse and recycling of processing by-products. Moreover, even if just 70 papers were retrieved from the Scopus database when searching the research terms 'wine' and 'precision viticulture' in the title and abstract research fields, the increasing adoption of digital technologies, including hyperspectral imaging, in grape growing might help to improve its sustainability because of

the use of drones, robots, satellites and sensors to capture aerial images of the vines informing about soil quality, unwanted weeds, vine diseases, and smoke-affected vines (Brunori et al. 2020), and thus pilot-targeted application of fertilisers and pesticides.

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Table S1. List of terms used for the creation of query strings: Group 1-Wine; Group 2-Grape; Group 3-combined made of the terms used in Groups 1 and 2; and Groups 4 and 5, where some specific terms excluded publication inherent to different topics.

Table S2. Group A refers to some terms that identify the main types of products, Group B to terms referring to molecules or analytical procedures, Group C are a series of terms related to aspects of research and Group D to grape cultivars, Group E to grape diseases.

Table S3. Number of publications for authors, affiliation, and countries, as extracted from the Grape-, and Wine-databases when including or excluding the specialised wine journals and referring to the 1950–2020 period.

Table S4. Comparison among the documents produced by the first ten publishing countries during the periods, 2020–

2016, 2020–2011 and 2010–2001, together with their proportion with respect to overall number of publications relative to the wine sector as retrieved throughout the overall 2020–1950 period.

Table S5. Number of publications for affiliation, extracted from the three W-, G- and W + G-databases for the 1950–2020 period.

Table S6. Journals selected on the base of the number of articles published, citations received, quartile position, Scimago Journal Rank, scientific impact, a citations per paper, in the Wine, Grape and Wine + Grape-databases over the 1950–2020 period.

Table S7. Authors ranked by the number of articles published, together with the country of origin, number of citations, and CPP index in the 1950–2020 period.