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Review article

Bibliometric analysis of the Spanish scientific production in Infectious Diseases and Microbiology (2014–2021)

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ABSTRACT

Introduction: The profound impact of the Covid-19 pandemic, together with other factors such as globalisation and climate change, has emphasised the growing relevance of Infectious Diseases and Microbiology.
Methods: The Spanish scientific production in both categories of the *Web of Science* databases over the period 2014–2021 has been analysed.
Results: 8037 documents have been identified in Infectious Diseases and 12008 documents in Microbiology (6th most productive country worldwide in both cases, with growth rates of 41% and 46.2%, respectively). Both areas present a high degree of international collaboration (45-48% of the documents) and between 45–66% of the documents have been published in journals of excellence (first quartile) according to the rankings of the Journal Citation Reports.
Conclusions: Spain is in a prominent position worldwide in both areas, with an outstanding scientific production in journals of high visibility and impact.

Análisis bibliométrico de la producción científica española en Enfermedades Infecciosas y en Microbiología (2014–2021)

Palabras clave:
Enfermedades infecciosas
Microbiología
Producción científica
Estudio bibliométrico
España

RESUMEN

Introducción: El profundo impacto que ha tenido la pandemia de Covid-19 junto a otros factores como la globalización o el cambio climático, ha enfatizado la relevancia creciente que tienen las Enfermedades Infecciosas y la Microbiología.
Métodos: Se ha analizado la producción científica española en ambas categorías de la *Web of Science* a lo largo del período 2014–2021.
Resultados: Se han identificado 8037 documentos en Enfermedades Infecciosas y 12008 documentos en Microbiología (6º país más productivo a nivel mundial en ambos casos, con tasas de crecimiento del 41% y 46,2%, respectivamente). Ambas áreas presentan una elevada colaboración internacional (45-48% de los documentos) y entre el 45-66% de los documentos han sido publicados en revistas de excelencia (primer cuartil) según los ránquines del *Journal Citation Reports*.
Conclusiones: España se sitúa en una destacada posición a nivel mundial en ambas áreas, con una destacada producción científica en revistas de elevada visibilidad e impacto.

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Introduction

The profound impact that the COVID-19 pandemic has had at all levels (health, social, political and economic), together with other factors such as population mobility fostered by globalisation, migratory phenomena, climate change or food security, has influenced the growing relevance of research both in the area of infectious diseases and microbiology, as has been revealed by the studies that have analysed the development of research in these fields.[1–5]

Different bibliometric studies have highlighted the relevance that Spanish research has had both in the field of infectious diseases[6–12] and microbiology[13–15] in the European and global context. One of the most recent contributions, a study by Ramos et al.[16] that analysed the scientific production collected in the journals of the infectious diseases and microbiology categories of the Web of Science Core Collection 2000 and 2013, highlighted the good level of Spanish research in both areas. In infectious diseases, the scientific production of Spain was in fourth position worldwide, with a contribution of 5.7%. In microbiology, Spain was ranked sixth, contributing 5.8% of the world's scientific production in the category. In 2014, the country's production in both areas was ahead of that for scientific activity as a whole, which represented 3.25%, placing it as the 10τη most productive country.[17] Moreover, the contribution in both categories was above that of other consolidated clinical care specialties, with an outstanding research projection, and increased notably throughout the period analysed, with growth rates of 131% and 45.8%, respectively.[16]

After these years of growth, it is currently of utmost interest not only to determine the evolution of scientific production and the positioning of Spain, both in the area of infectious diseases and in microbiology, but also to evaluate the relevance or excellence of the research in terms of its visibility and impact, in a context in which there is increasing emphasis on the need to make a qualitative leap in the processes of evaluation of research activity and scientific development, once a good level of research development has been reached in quantitative terms, considering the number of documents published.

The main objective of this study was to update the information on Spain's contribution to global research in the areas of infectious diseases and microbiology. To achieve this, the research generated throughout the period 2014–2021 was analysed. The following were set as specific objectives: a) to compare the Spanish scientific production in infectious diseases and microbiology with that generated by other medical specialties throughout the aforementioned period; b) to determine the degree of excellence of the research by measuring the visibility and impact of the publications; and c) to identify some of the variables that may influence the degree of citation of publications: open access publications, research funding, degree of collaboration and "altmetric" indicators of document use.

Methods

To conduct the study, the articles, reviews and letters published between 2014 and 2021 corresponding to the categories "infectious diseases" and "microbiology" from the databases of the Web of Science Core Collection were identified (*WC = Infectious diseases OR WC = Microbiology*) *AND* (*DT = "ARTICLE" OR "REVIEW" OR "LETTER"*) *AND PY = (2014–2021)*.

A database was generated with the world scientific production by countries, in order to analyse the Spanish contribution in both areas and to compare the number of documents published with the economic investments in research and the population of each country. Following standard procedure in bibliometric studies, an article was considered to be of Spanish authorship when the institutional affiliation of at least one of the signing authors was a Spanish institution. Meanwhile, documents from England, Scotland, Wales and Northern Ireland were unified as from the United Kingdom.

Subsequently, two specific databases were created with the documents on infectious diseases and microbiology signed by researchers affiliated with Spanish institutions, in order to analyse in detail the research activity in these areas. In addition, to compare the Spanish scientific production with other consolidated medical disciplines, the documents (articles, reviews and letters) with Spanish participation in the indicated period (2014–2021) were identified in the categories of neurology, cardiovascular system, endocrinology and metabolism, nephrology and urology, pulmonology and rheumatology.

The following aspects were analysed:

a) Scientific production. The Spanish scientific production in infectious diseases and microbiology was analysed in the context of global production, in relation to other areas or clinical care specialties and the contribution of the research considering the investment and population of the different countries, using the following indicators for the period as a whole:
   - Number of documents by country and percentage of global scientific production that they represent.
   - Number of documents per country for each percentage point of gross domestic product (GDP) allocated to research activities and number of documents per GDP per capita (US$). The data on research and development expenditure (percentage of GDP dedicated to research) and on population were obtained from the United Nations Educational, Scientific and Cultural Organization (UNESCO), and the GDP per capita was calculated based on the average for the period 2014–2021 according to data provided by the World Bank and the Organisation for Economic Cooperation and Development (OECD).
   - Number of documents by thematic category worldwide (infectious diseases, microbiology, neurology, cardiovascular system, endocrinology and metabolism, nephrology and urology, pulmonology and rheumatology) and Spain's position in them.
   - In order to analyse the diachronic evolution of Spanish research activity in infectious diseases and microbiology, the number of documents per year of publication and the growth rate in the period as a whole were also estimated.
b) Visibility and impact of the research. The visibility of Spanish research in infectious diseases and microbiology was estimated from relative indicators based on the relative position occupied by the journals in which the documents were published in the citation rankings of the Clarivate Analytics Web of Science; and the impact was determined from different indicators based on the citations received by the documents:
   - Impact Factor (IF). The IF of the Web of Science has traditionally been the reference indicator used in research evaluation processes, particularly in the field of health sciences. In this regard, the IF of the year 2020 of the most productive journals (>99 documents) was estimated, along with the relative position of the journal in the ranking of the set of journals in each of the categories analysed and the quartile occupied by it.
   - *Journal Citation Indicator* (JCI). The JCI is a standardised measure of impact of the citations that the articles and reviews of a journal have received in its thematic category, such that the average value is 1. This means that a journal with a JCI greater than 1 has received a citation grade higher than the average for its category.
   - Total number of citations received and average number of citations per document.

- Percentage of documents not cited.
- Variables associated with the citation. The relationship between the citations received by the documents and their open access publication, the research funding, the collaboration and the number of countries that participated in the publications was also analysed.

c) Collaboration, international projection and leadership of the research. The degree of collaboration (national and international) and the evolution of international collaboration were estimated for the whole of Spanish scientific production in infectious diseases and microbiology, as well as the main collaborating countries. The concurrence of two or more Spanish institutional affiliations in the same document was considered to be a national collaboration, and an international collaboration when institutions linked to two or more countries participated. Both types of collaboration can occur simultaneously in the same document. The following indicators were calculated:
   - Number of documents with national and international collaboration and percentage of the total number of documents.
   - Percentage of documents with international collaboration with the main collaborating countries.

   Given the widespread use of cooperative practices in the analysed area, the following aspects were analysed in relation to documents with international collaboration as an approximation to the leadership of Spanish research, understood as participating in relevant positions in the signing of documents or in the role of corresponding authors:
   - Number and percentage of documents in which the first and last signatory is an author affiliated with a Spanish institution.
   - Number and percentage of documents in which the corresponding author is affiliated with a Spanish institution.

d) Altmetric indicators. The altmetric indicators estimate the "use" made of the documents based on measures such as consultation and download of the documents. These indicators have gained significant acceptance and recognition over the last few years, as a complement to the traditional bibliometric indicators. In this study, the following altmetric indicator was collected:
   - Number of documents that have been consulted at least once. This value was estimated from the usage count of the documents ("Usage Count, since 2013"), a measure that is interpreted as the degree of interest that a document arouses in order to satisfy the informational needs of users, either by clicking on the link to access the full text of the document or saving it using an application for bibliographic management.
   - Finally, the existing Pearson correlation coefficient between the altmetric indicators and the citations received by the documents was estimated.

Results

Analysis of the Spanish scientific production in infectious diseases in the international context and in relation to other medical specialties

Evolution of the scientific production collected in the Web of Science Core Collection

During the study period (2014–2021), 162,524 documents published in journals assigned to the infectious diseases category were identified, considering the documentary typologies "article", "letter" and "review". Of these, 82.1% were articles (n = 133,449), 9% were reviews (n = 14,564) and 8.9% were letters (n = 14,511). The Spanish scientific production during this period was 8037 documents: 6343 articles (78.9%), 955 reviews (11.9%) and 739 letters (9.2%).

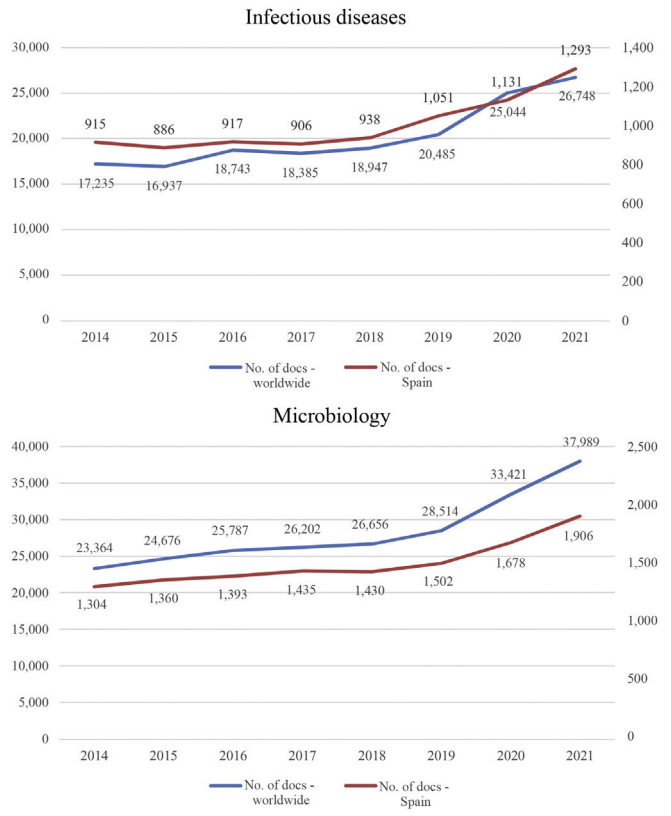

Figure 1. Evolution of the number of documents published worldwide and in Spain in the categories "infectious diseases" and "microbiology" in the Web of Science Core Collection (2014–2021).

The evolution of the total number of documents by year of publication is shown in Fig. 1. The increase in global production throughout the study period is noteworthy, which went from 17,235 documents in 2014 to 26,748 in 2021, with a growth rate of 55% (R^2 = 0.76). Spanish production in this period also increased significantly, from 915 documents in 2014 to 1293 in 2021, with a growth rate of 41% (R^2 = 0.82).

Spain ranked sixth in global scientific production, contributing 4.95% of the documents published in this specialty in the period 2014–2021, only behind the USA, the United Kingdom, China, France and Australia (Table 1). In relation to other specialties taken as a reference for comparison (Table 2), the category of infectious diseases is ranked, together with microbiology, as the most prominent, above the 10th and 11th positions occupied by categories such as clinical neurology or cardiovascular system, among other specialties. If we consider the research effort, measured through the number of documents per GDP devoted to research activities, Spain (6419.1) lies only behind the United Kingdom (10,918.2) among the most productive European countries. When also considering GDP per capita, Spain is increasing its leadership position in relation to many other countries (Table 1).

Publication journals: research visibility

The journal in the infectious diseases category with the largest number of documents published is *Enfermedades Infecciosas y Microbiología Clínica* [Infectious Diseases and Clinical Microbiology], with 1077 documents, which represents 13.4% of the Spanish scientific production in the subject area. Next is the *Journal of Antimicrobial Chemotherapy* with 474 documents (5.9%), followed by *Clinical Infectious Diseases*, with 331 documents (4.1%). Table 3 shows the most productive journals (≥100 documents). Regarding the visibility of the research, it should be noted that 10 of the 23

Table 1
Distribution of the global scientific production on "infectious diseases" and "microbiology" by countries collected in the Web of Science Core Collection throughout the period 2014–2021.

Infectious diseases					Microbiology				
Country	No. of documents published (total 149,269)	%	No. of documents for each percentage point of GDP allocated to research activities	No. of documents per GDP per capita	Country	No. of documents published (total 233,771)	%	No. of documents for each percentage point of GDP allocated to research activities	No. of documents per GDP per capita
USA	54,191	33.343	18,183	0.88	USA	63,890	28.194	21,437.3	1.04
United Kingdom	18,162	11.17	10,918.2	0.41	China	34,817	15.364	16,159.7	3.69
China	14,930	9.186	6929.5	1.58	Germany	16,832	7.428	5552.8	0.37
France	11,501	7.076	5138.4	0.29	France	14,509	6.403	6482.4	0.36
Australia	8488	5.223	4523.4	0.15	United Kingdom	14,488	7.51	8709.6	0.33
Spain	8037	4.945	6419.1	0.28	**Spain**	12,008	5.299	9590.7	0.42
Germany	7764	4.777	2561.3	0.17	India	11,272	4.974	16,643.6	5.94
Brazil	7679	4.725	6209.2	0.85	Japan	10,073	4.445	3124.7	0.26
Italy	7644	4.703	5440.7	0.23	Canada	9289	4.099	5514.8	0.20
Canada	6702	4.124	3978.9	0.14	Brazil	9119	4.024	7373.6	1.01
Netherlands	6350	3.907	2911.7	0.12	Italy	9094	4.013	6472.7	0.27
Switzerland	6254	3.848	2034	0.07	Australia	8589	3.790	4577.2	0.15
Japan	6214	3.823	1927.6	0.16	South Korea	8314	3.669	1921.2	0.27
India	6158	3.789	9092.5	3.25	Netherlands	7196	3.176	3299.6	0.14
South Africa	5464	3.362	7703.6	0.84	Switzerland	5912	2.609	1922.8	0.07
Belgium	3841	2.363	1379.8	0.08	Belgium	4612	2.035	1656.8	0.10
Thailand	3756	2.311	4390.8	0.56	Sweden	4209	1.857	1271.8	0.08
Sweden	3652	2.247	1103.5	0.07	Iran	4176	1.843	5877.6	0.88
Republic of Korea	2928	1.802	676.6	0.09	Denmark	4175	1.842	1404.5	0.07
Taiwan	2541	1.563	–[a]	–[a]	Russia	3874	1.710	3609.9	0.35

[a] Without GDP data.

Table 2
Global and Spanish scientific production in different categories of the Journal Citation Report in the period 2014–2021.

Categories	Total no. of documents in the category	No. of documents from Spain	% of documents from Spain in the category	Position of Spain in the category worldwide
Infectious diseases	162,524	8037	4.95	6
Microbiology	226,609	12,008	5.30	6
Neurology	301,885	11,818	3.91	11
Cardiovascular system	228,142	9285	4.07	10
Endocrinology and metabolism	175,977	6362	3.62	11
Nephrology and urology	112,903	4836	4.28	10
Pulmonology	109,232	4833	4.42	10
Rheumatology	54,187	3028	5.59	10

most productive journals are in the first quartile of the ranking of journals based on IF (including *PLOS Neglected Tropical Diseases*); and 12 journals have a JCI above one, which means that 50.74% of the documents have been published in journals of excellence considering this last indicator (with a JCI that places them in Q1), a value that amounts to 62.98% of the documents published in international journals (Table 3).

Degree of collaboration and international projection of the research

Overall, 45.3% of the documents ($n = 3645$) have been signed in international collaboration, although it should be noted that an upward trend in international collaboration was observed throughout the period analysed, going from 38.1% in 2014 to 46.4% in 2021. The highest degree of collaboration is with researchers from the USA, who have collaborated in 15.1% ($n = 1214$) of the documents, followed by the United Kingdom (14.4%, $n = 1158$) and France (11%, $n = 883$). Fig. 2 shows the main countries with which collaboration links have been established (>2% of the documents). In 56.98% ($n = 2077$) of the documents with international collaboration, Spanish researchers in the area of infectious diseases have had a prominent role in leading the research, either as first signatories (33.31%, $n = 1214$), last signatories (32.92%, $n = 1200$) or corresponding authors (35.99%, $n = 1312$).

Impact of the research

The documents analysed received a total of 117,871 citations, which places the average number of citations per document at 14.7 ± 33.9, with a greater citation of reviews (25.7 ± 43.6) compared to articles (15 ± 34.4) and letters (3.6 ± 10.4). Also noteworthy is the low percentage of publications not cited (only 4–6 % of the documents in the 2014–2018 period).

Analysis of the Spanish scientific production in microbiology in the international context and in relation to other medical specialties

Evolution of the scientific production collected in the Web of Science Core Collection

During the study period (2014–2021), 226,609 documents published in the microbiology category were identified: 88% were articles ($n = 199,399$), 9.3% were reviews ($n = 21,087$) and 2.7% were letters ($n = 6123$). The Spanish scientific production during this period was 12,008 documents, comprising 10,035 articles (83.6%), 1072 reviews (8.9%) and 901 letters (7.5%). Spain ranked sixth in global scientific production, contributing 5.3% of the documents

Table 3
Main journals for the categories "infectious diseases" and "microbiology" in which Spanish authors published their documents.

Journals in the "infectious diseases" category	No. of docs	% of total docs	Impact factor (IF) 2020 – Journal position – Quartile	*Journal Citation Indicator (JCI) 2020 – Journal position - Quartile*
Enfermedades Infecciosas y Microbiología Clínica [Infectious Diseases and Clinical Microbiology]	1077	13.401	1.731 – 82/93 – Q4	0.45 – 83/118 – Q3
Journal of Antimicrobial Chemotherapy	474	5.898	5.790 – 14/93 – Q1	1.51 – 8/118 – Q1
Clinical Infectious Diseases	331	4.118	9.079 – 3/93 – Q1	2.13 – 3/118 – Q1
PLOS Neglected Tropical Diseases[a]	329	4.094	–	–
Clinical Microbiology and Infection	328	4.081	8.067 – 5/93 – Q1	1.61 – 6/118 – Q1
Antibiotics-Basel	256	3.185	4.639 – 26/93 – Q2	1.00 – 34/118 – Q2
European Journal of Clinical Microbiology & Infectious Diseases	248	3.086	3.267 – 52/93 – Q3	0.77 – 53/118 – Q2
Transboundary and Emerging Diseases	245	3.048	5.005 – 23/93 – Q1	2.07 – 4/118 – Q1
Aids	201	2.501	4.177 – 32/93 – Q2	1.09 – 26/118 – Q1
BMC Infectious Diseases	199	2.476	3.090 – 57/93 – Q3	0.82 – 50/118 – Q2
Malaria Journal	195	2.426	2.979 – 58/93 – Q3	0.93 – 41/118 – Q2
Journal of Infection	189	2.352	6.072 – 10/93 – Q1	1.24 – 19/118 – Q1
Pediatric Infectious Disease Journal	187	2.327	2.129 – 79/93 – Q4	0.73 – 59/118 – Q2
International Journal of Antimicrobial Agents	177	2.202	5.283 – 17/93 – Q1	1.27 – 17/118 – Q1
Emerging Infectious Diseases	146	1.817	6.883 – 7/96 – Q1	1.48 – 9/118 – Q1
Eurosurveillance	142	1.767	6.307 – 8/93 – Q1	1.52 – 7/118 – Q1
Journal of Infectious Diseases	137	1.705	5.226 – 18/93 – Q2	1.40 – 13/188 – Q1
International Journal of Infectious Diseases	133	1.655	3.623 – 45/93 – Q2	0.91 – 44/118 – Q2
HIV Medicine	115	1.431	3.180 – 54/93 – Q3	0.97 – 35/118 – Q2
Diagnostic Microbiology and Infectious Disease	114	1.418	2.803 – 61/93 – Q3	0.74 – 58/118 – Q2
Lancet Infectious Diseases	112	1.394	25.071 – 1/93 – Q1	5.97 – 1/118 – Q1
Transplant Infectious Disease	104	1.294	2.228 – 73/93 – Q4	0.56 – 75/118 – Q3
Infection Genetics and Evolution	101	1.257	3.342 – 51/93 – Q3	0.89 – 46/118 – Q2
Journals in the "microbiology" category	No. of docs	% of total docs	Impact factor (IF) 2020 – Journal position – Quartile	*Journal Citation Indicator (JCI) 2020 – Journal position - Quartile*
Frontiers in Microbiology	1166	9.710	5.640 – 28/136 – Q1	1.09 – 36/151 – Q1
Enfermedades Infecciosas y Microbiología Clínica [Infectious Diseases and Clinical Microbiology]	1077	8.969	7.31 – 124/136 – Q4	0.45 – 120/151 – Q4
Revista Española de Quimioterapia [Spanish Journal of Chemotherapy]	711	5.921	1.553 – 125/136 – Q4	0.30 – 132/151 – Q4
Journal of Antimicrobial Chemotherapy	474	3.947	5.790 – 26/136 – Q1	1.51 – 16/151 – Q1
Antimicrobial Agents and Chemotherapy	463	3.856	5.191 – 39/136 – Q2	1.40 – 18/151 – Q1
Microorganisms	390	3.248	4.128 – 52/136 – Q2	0.78 – 64/151 – Q2
International Journal of Food Microbiology	340	2.831	5.277 – 36/136 – Q2	1.40 – 18/151 – Q1
Clinical Infectious Diseases	331	2.756	9.079 – 12/136 – Q1	2.13 – 7/151 – Q1
Clinical Microbiology and Infection	328	2.732	8.067 - 13/136 – Q1	1.61 – 15/151 – Q1
Environmental Microbiology	328	2.732	5.491 – 30/136 – Q1	1.27 – 27/151 – Q1
Microbiology Resource Announcements[b]	257	2.140	–	0.19 – 141/151 – Q4
European Journal of Clinical Microbiology & Infectious Diseases	248	2.065	3.267 – 78/136 – Q3	0.77 – 66/151 – Q2
Food Microbiology	221	1.840	5.516 – 29/136 – Q1	1.40 – 18/151 – Q2
Applied and Environmental Microbiology	211	1.757	4.792 – 43/136 – Q2	1.08 – 38/151 – Q2
International Journal of Systematic and Evolutionary Microbiology	211	1.757	2.747 – 9/136 – Q3	0.67 – 79/151 – Q3
Pathogens	186	1.549	3.492 – 67/136 – Q2	0.61 – 89/151 – Q3
International Journal of Antimicrobial Agents	177	1.474	5.283 – 35/136 – Q1	1.27 – 27/151 – Q1
Journal of Fungi	163	1.357	5.816 – 24/136 – Q1	0.97 – 47/151 – Q2
PLOS Pathogens	163	1.357	6.823 – 20/136 – Q1	1.85 – 9/151 – Q1
Veterinary Microbiology	156	1.299	3.293 – 76/136 – Q3	1.38 – 22/151 – Q1
Journal of Clinical Microbiology	154	1.282	5.948 – 22/136 – Q1	1.27 – 27/151 – Q1
Microbial Biotechnology	138	1.149	5.813 – 25/136 – Q1	1.12 – 34/151 – Q1
Journal of Infectious Diseases	137	1.141	5.226 – 38/136 – Q2	1.40 – 18/151 – Q1
mBio	131	1.091	7.867 – 15/136 – Q1	1.82 – 10/151 – Q1
Frontiers in Cellular and Infection Microbiology	128	1.066	5.293 – 33/136 – Q1	0.94 – 50/151 – Q2
Diagnostic Microbiology and Infectious Disease	114	0.949	2.803 – 90/136 Q3	0.74 – 71/151 – Q2
Systematic and Applied Microbiology	113	0.941	4.022 – 53/136 – Q2	0.97 – 47/151 – Q2

Table 3 (*Continued*)

Journals in the "infectious diseases" category	No. of docs	% of total docs	Impact factor (IF) 2020 – Journal position – Quartile	*Journal Citation Indicator (JCI) 2020 – Journal position - Quartile*
ISME Journal	111	0.924	10.302 – 10/136 – Q1	2.82 – 5/151 – Q1
Microbial Ecology	111	0.924	4.552 – 45/136 – Q2	1.35 – 25/151 – Q1
Life-Basel	107	0.891	4.792 – 43/136 – Q2	1.08 – 38/151 – Q2
Journal of Applied Microbiology	100	0.833	3.772 – 57/136 – Q2	0.81 – 58/151 – Q2

[a] The PLOS Neglected Tropical Diseases documents are assigned to the categories "infectious diseases", "parasitology" and "tropical medicine" in the Science Citation Index, although the Journal Citation Reports only includes the indicators corresponding to the journal in these last two categories, in all cases (IF and JCI) always in Q1.

[b] Microbiology Resource Announcements does not have an impact factor (only a JCI) because it is in the Emerging Sources Citation Index (ESCI).

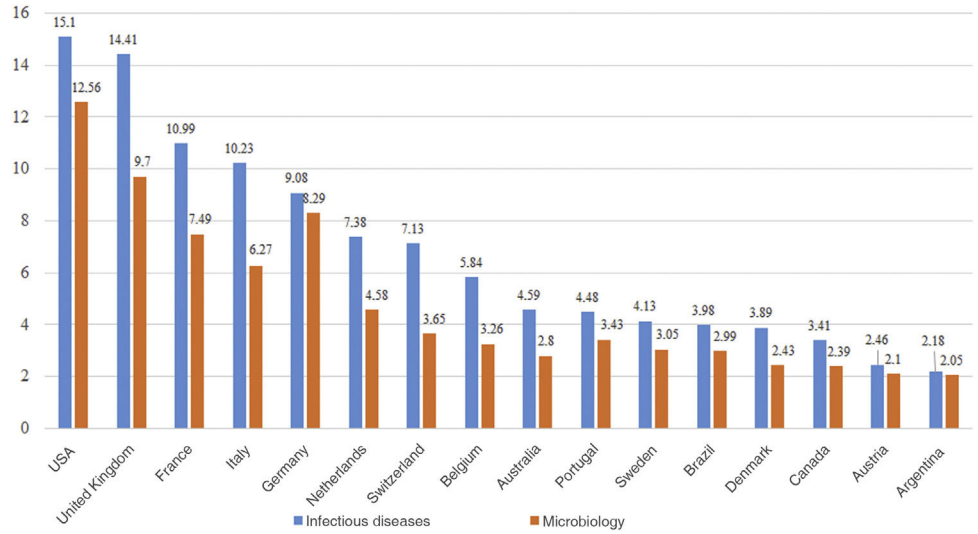

Figure 2. Main collaborating countries and percentage of documents signed in international collaboration in Spain in the categories "infectious diseases" and "microbiology" collected in the Web of Science Core Collection (2014–2021).

published in this specialty in the period 2014–2021, only behind the USA, China, Germany, France and the United Kingdom (Table 1). Spain is in sixth position in terms of global contribution in the category, above the rest of the medical specialties taken as a reference (Table 2), with a research effort in terms of the economic resources invested only behind the USA, India and China in the case of the number of documents per percentage point of GDP allocated to research activities, and the leading European country if the number of documents per GDP per capita is considered (Table 1).

The evolution of the total number of documents by year of publication is shown in Fig. 1. The increase in the number of documents throughout the study is noteworthy, which went from 23,364 documents published in 2013 to 37,989 in 2021. The growth rate was 62.6% ($R^2 = 0.83$). Spanish production in microbiology during this period also grew, from 1304 documents in 2014 to 1906 in 2021, which places the growth rate at 46.2% ($R^2 = 0.81$).

Publication journals: research visibility

The journal in the microbiology category in which the largest number of documents were published was *Frontiers in Microbiology*, with 1166 documents, representing 9.7% of the scientific production in the category, followed by *Enfermedades Infecciosas y Microbiología Clínica*, with 1077 documents (9%) and *Revista Española de Quimioterapia* [Spanish Journal of Chemotherapy], with 711 documents (5.9%). Table 3 shows the journals with the highest number of published documents (≥100 documents). Fourteen of the 31 most productive journals in the microbiology area in which research papers have been published are in the first quartile of the IF (24 if the first and second quartiles are considered), and 19 of them have a JCI greater than 1. In terms of published documents, this last indicator means that 52.63% of the documents have been published in journals of excellence (with a JCI that places them in Q1), a value that rises to 65.78% of the documents published in international journals (Table 3).

Degree of collaboration and international projection of the research

Of the documents published in the microbiology category, 48.2% ($n = 5793$) were signed in international collaboration, which increased from 42.4% in 2014 to 51.4% in 2021; 12.56% of the papers ($n = 1508$) were published in collaboration with researchers in the USA, 9.7% ($n = 1160$) with researchers in the UK and 8.3% ($n = 996$) with researchers in Germany. Fig. 2 shows the distribution of the main countries with which researchers in microbiology from Spanish institutions have collaborated. In total, 67.87% ($n = 3932$) of the documents with international collaboration in which Spanish microbiology researchers participated were led by them as first signatories (41.27%, $n = 2391$), last signatories (37.16%, $n = 2153$) or corresponding authors (42.65%, $n = 2471$).

Impact of the research

The documents analysed received a total of 194,151 citations, which places the average number of citations per document at 16.2 ± 51.7, with reviews being the most cited document type (37.5 ± 87.4), compared to articles (15.2 ± 48) and letters (2 ± 5). The percentage of publications not cited was 4–7 % of the documents in the period 2014–2021.

Identification of the variables associated with the increased citation of publications and metrics of document use

Our study has established for both infectious diseases and microbiology that the publications disseminated in open access, those that received funding, those carried out in international

Table 4
Link between the degree of citation (mean citations per document) and different bibliographic variables in the Spanish scientific production in "infectious diseases" and "microbiology".

Variable	Infectious diseases - mean citations/doc. (no. of docs)	Microbiology - mean citations/doc. (no. of docs)
Open access		
Yes	18.6 (n = 4448)	19.3 (n = 7665)
No	9.8 (n = 3589)	10.5 (n = 4343)
Funded research		
Yes	18.6 (n = 5002)	19.2 (n = 8929)
No	7.9 (n = 3035)	7.4 (n = 3079)
International collaboration		
Yes	21.1 (n = 3645)	20.7 (n = 5793)
No	9.3 (n = 4392)	11.9 (n = 6215)
Type of collaboration		
International only	21.1 (n = 1673)	22.1 (n = 3051)
National only	9.42 (n = 3759)	10.9 (n = 4552)
Both	21.1 (n = 1972)	19.2 (n = 2742)
Without collaboration	8.8 (n = 633)	14.7 (n = 1663)
No. of collaborating countries		
2	13.4 (n = 1382)	15.7 (n = 3077)
3	15.8 (n = 696)	17.1 (n = 1302)
4	18.4 (n = 401)	20.4 (n = 557)
5	24.9 (n = 283)	28.6 (n = 288)
6	30.9 (n = 183)	58.8 (n = 137)
7	22.2 (n = 147)	24.2 (n = 103)
8	28.1 (n = 93)	77.4 (n = 57)
9	39.4 (n = 78)	66.3 (n = 48)
10	52.4 (n = 63)	54.6 (n = 58)
Between 11 and 15	37.8 (n = 192)	52.4 (n = 114)
Between 16 and 20	47.8 (n = 62)	71.6 (n = 22)
More than 20	74.9 (n = 64)	36 (n = 30)

collaboration, and those with a greater number of participating countries, are associated with a higher degree of citation. Table 4 shows the average citations per document considering the aforementioned variables.

Regarding the use of documents, 88.93% (n = 7147) in the category of infectious diseases and 92% (n = 11,047) in microbiology have been downloaded or saved in a reference management application, with an average number of "uses" per document of 7.06 ± 11.58 and 14.63 ± 27.08, respectively. A moderate degree of correlation was verified, with values of 0.56 in both categories analysed.

Discussion

Our study confirms the good level of Spanish research, both in infectious diseases and in microbiology, during the period 2014–2021. It should be noted that Spain continues to have one of the world's highest scientific production rates in both disciplines, with relative contributions higher than those of other medical specialties with an outstanding healthcare, teaching and research trajectory, as was the case in the period 2000–2013. In infectious diseases, although Spain has gone from fourth to sixth position in the world ranking of scientific production,[16] it continues to be the third most productive European country, with a contribution of 4.95% of the total documents published in this specialty worldwide, behind only the USA, the United Kingdom, China, Australia and France. In microbiology, with 5.3% of scientific production, Spain continues to occupy the fourth position in Europe and the sixth in the world, only behind the USA, China, Germany, France and the United Kingdom, since, although it has also been surpassed by China, it has overtaken Japan. The main novelty compared to the study by Ramos et al.[16] is the positioning of China, which has experienced a considerable increase in the number of publications that have ranked it as the third most productive country worldwide, surpassing even the USA in some of the main areas of interest for research in microbiology.[1]

If economic parameters and populations are considered, Spain stands out even more in both areas, being the leading country together with China, as also highlighted by the study by Moral-Muñoz et al.,[18] which should serve to warn about the relevance of investment in research reference areas in order to continue maintaining that position in an increasingly competitive and global environment. Although there are numerous factors that can affect the scientific productivity of researchers, the review by Wahid et al.[19] identified *three personal factors* (time dedicated to research activities, academic rank and training of researchers) and *two circumstantial factors* (funding and collaboration) as those referred to most frequently in the literature and that may have a greater influence on this variable. For this reason, the development of funding and cooperative initiatives, such as the Red Española de Investigación en Patología Infecciosa (REIPI) [Spanish Network for Research in Infectious Diseases] and the Red de Investigación en Sida (RIS) [AIDS Research Network], which have been promoted over recent decades and favoured both the productivity and the citation and impact of the research,[20] is crucial. In the particular case of scientific production in microbiology and infectious diseases in Spain, the improvement in research results can be put down to a greater professional and social appreciation of research activity in this field, recognition of the specialty of infectious diseases and the promotion of clinical microbiology, as well as the consolidation of powerful and well-financed structures and platforms for the development of cooperative research. The thematic networks developed in the last two decades have led to a significant boost both in productivity and in the citation and impact of research,[20] which should be strengthened with the recent creation of the Centro de Investigación Biomédica en Red de Enfermedades Infecciosas (CIBERINFEC) [Centre for Networked Biomedical Research in Infectious Diseases].

Beyond the significant growth in Spanish scientific production identified in this study, both in infectious diseases (41% growth rate) and in microbiology (46%), although with values somewhat lower than the global growth rates for the period 2014–2021 (which stood at 55% and 63%, respectively), it is worth highlighting as the most significant aspect the important qualitative leap experienced by Spanish research, with citation values that, in the case of research in infectious diseases, have doubled those reported in the study by Íñigo et al.[11] for the period 2000–2009. Added to this is the prominent presence of Spanish research in journals with high impact and visibility, a reflection of the state of maturity reached by the research and largely fostered by the important collaboration and link with networks and countries with the greatest scientific development, which is much more marked than in previous studies.[17,21]

The journal *Enfermedades Infecciosas y Microbiología Clínica* [Infectious Diseases and Clinical Microbiology], published by the Spanish Society of Infectious Diseases and Clinical Microbiology and included in both categories, published more documents by Spanish authors on infectious diseases than any other journal, and ranked second in terms of microbiology publications. In the case of this last specialty, this highlights the position achieved in the period 2000–2013 by another Spanish journal, *Revista Española de Quimioterapia* [Spanish Journal of Chemotherapy], ranked as the third most productive, reflecting the reference role that both publications play as a vehicle for communication of the community of professionals linked to health care and for clinical microbiologists.[21] Participation in these Spanish journals goes hand in hand with outstanding scientific production in prominent reference journals worldwide due to their high visibility, focused on the development of such aspects as antimicrobial therapies, AIDS or research and monitoring of emerging infectious diseases.

The results of this study confirm the value of open publication to increase the impact of research, as well as the relevance of funding and scientific collaboration for the advancement of knowledge. The importance of international collaboration for the promotion of first-class research, as shown in this study, contrasts with the dynamics of knowledge generation in exceptional circumstances such as those associated with different epidemic outbreaks. In terms of research, the initial stages of the COVID-19 pandemic were characterised, as some studies have warned, by a low availability and dissemination speed of information and by a reduced and deficient degree of international collaboration.[22,23] This highlights the relevance of policies and scientific structures that foster conditions that favour rapid and effective international collaboration in emergency situations, in addition to the importance of promoting research and collaboration with countries and geographical areas more susceptible to generating outbreaks that can quickly spread around the world.[24]

The relationship between altmetric indicators and bibliometric citation indicators, also found in other studies in the field of infectious diseases,[25] highlights the interest that they may have as a complement to production and citation indicators, and for monitoring the relevance and interest of newly published studies.

As limitations of the study, it is worth noting those inherent to the information source consulted and the search strategy used, repeatedly indicated as such in the literature.[7,9,11,17] In this sense, it should be noted that the 2020 edition of the SCImago Journal Rank, which includes the journals indexed in the Scopus database, included 308 journals in the category of infectious diseases compared to 93 in the Journal Citation Reports, and 242 journals were included in microbiology (categories "microbiology" and "microbiology, medical") compared to 137 in the Journal Citation Reports. This would have significantly increased the number of documents analysed, for example, by 20% in the case of infectious diseases, with 10,282 documents with Spanish participation included in this category in the period 2014–2021 (compared to 8037 in our study), although communications to congresses are included in this calculation. It should also be borne in mind that a broad vision of the research was chosen, including letters (despite the fact that some of them may be limited to comments of less scientific relevance) and reviews; and that the search strategy used ignored the publications of Spanish researchers in the field of infectious diseases and microbiology in journals of other thematic categories that are closely related to clinical practice in the areas analysed, such as general and internal medicine, as well as participation in journals in other related areas of knowledge, such as virology, parasitology or tropical medicine. In this sense, by way of example, in a study on the scientific production on HIV-AIDS in Spain based on an exhaustive thematic search, along with infectious diseases and microbiology, other areas such as immunology (24.92% of the documents), virology (18.79%) and pharmacology (14.57%) had a notable presence,[20] although it must be taken into account that this presence can also be explained in many cases to the cross-cutting nature of the diseases studied, HIV-AIDS in this case, and that specialised journals are the ones that bring together core knowledge and that establish the foundations and guide the development of a discipline. Nor should we forget the growing relevance of scientific production disseminated in multidisciplinary journals as a phenomenon that is altering the patterns of dissemination of knowledge and that has a particular influence in biomedical and clinical research,[26,27] but that is not associated with a decrease in the quality of the review processes, with fewer citations or as a mechanism to publish more easily. Warnings to this effect were raised by a study of the most prolific Spanish researchers in the area of medicine,[28] in addition to areas of emerging interest in relation to microbiology, such as research linked to One Health that highlights the relevance for human health of the approaches that link it to animal and environmental health, which is why they constitute aspects, together with the other limitations indicated, that must be considered in future studies. Despite the aforementioned limitations, the Web of Science databases constitute the main benchmark for evaluation and research excellence in the field of health sciences, and it is a widespread practice for bibliometric studies to characterise the development of research in the different disciplines from the specific publications collected in the different thematic categories, meaning that the analysis constitutes a good approximation to the development of research in the area.

The profound impact that the COVID-19 pandemic has had on scientific activity makes it of great interest, as a future line of work, to specifically analyse Spanish scientific production in this area in relation to global activity and the impact that it has had in the areas analysed, since it may have motivated an overestimation of the citation of these publications (and by extension of the journals) in the initial stages of the pandemic, as the study by Maillard et al. has shown.[29]

The main conclusions of our study are the following:

1 Spanish scientific production in the areas of infectious diseases and microbiology ranks as an outstanding global reference in the period 2014–2021 (6th most productive country in both categories), standing out even more in relation to other European countries and worldwide if population parameters or economic resources allocated to research activities are taken into account.
2 More than half of the Spanish scientific production in the areas of infectious diseases and microbiology has been published in journals with the greatest impact and visibility, positioned in the first quartile of the ranking of the main source of information for the evaluation of research in health sciences, the Journal Citation Reports, published by Clarivate Analytics.
3 Publication in open access journals, funded research, international collaboration, the number of countries participating in research and the altmetric indicators of document use are all variables associated with a higher degree of citation of scientific publications.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

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