




Review

Worldwide Research Trends on Wheat and Barley: A Bibliometric Comparative Analysis

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Abstract: Grain cereals such as wheat, barley, rice, and maize are the nutritional basis of humans and animals worldwide. Thus, these crop plants are essential in terms of global food security. We conducted a bibliometric assessment of scientific documents and patents related to wheat and barley through the Scopus database. The number of documents published per year, their affiliation and corresponding scientific areas, the publishing journals, document types and languages were metricized. The main keywords included in research publications concerning these crops were also analysed globally and clustered in thematic groups. In the case of keywords related to agronomy or genetics and molecular biology, we considered documents dated up to 1999, and from 2000 to 2018, separately. Comparison of the results obtained for wheat and barley revealed some remarkable different trends, for which the underlying reasons are further discussed.

Keywords: crop; cereals; agronomy; genetics; bibliometry

1. Introduction

Wheat (*Triticum* spp.) and barley (*Hordeum vulgare* L.) are two cereal crops that belong to the family Poaceae (order Poales). Wheat is a staple source of nutrients for around 40% of the world's population. Barley is mainly used for animal feed and for brewing, although it is also considered a principal food in regions where other major cereals cannot be grown.

The cultivation of wheat reaches far back into history. Wheat was one of the first domesticated food crops and for 8000 years has been the main food of the major civilizations of Europe, West Asia and North Africa. This is likely because of wheat's agronomic adaptability, ease of grain storage and ease of converting grain into flour for making many different foods [1]. Currently, wheat is the most widely grown crop in the world, on more than 218 million ha, and its world trade is greater than for all other crops combined. Wheat occupies a central place in human nutrition providing 20% of the daily protein and food calories. In terms of food security, it is the second most important food crop in the developing world after rice, because an estimated 80 million farmers rely on wheat for their livelihoods [1].

Roughly 90 to 95% of the wheat produced in the world is common or bread wheat (*Triticum aestivum* L. $2n = 42$, hexaploid, AABBDD genomes), which can be classified as hard wheat or soft wheat, depending on the grain hardness. Bread wheat is utilized mainly as flour (whole grain or refined) for the production of a large variety of leavened and flat breads, and for the manufacture of a wide variety of other baked products. The total world production also includes about 35–40 million tonnes of *T. turgidum* L. var. *durum* Desf. ($2n = 28$, tetraploid, AABB genomes), which is well adapted to the hot, dry conditions surrounding the Mediterranean Sea and similar climates in other world regions. This species is mainly used for making pasta and is often referred to either as “pasta wheat”

or “durum wheat”. Some durum wheat is milled into flour to manufacture medium-dense breads in Mediterranean and Middle Eastern countries and some into coarse durum grain grits used to produce couscous (cooked grits) in Arab countries [2]. Other wheat species are less cultivated although they play a major role in the expanding market in health foods. These are einkorn (*T. monococcum* L. subsp. *monococcum*, diploid, AA genomes), emmer (*T. turgidum* L. var. *dicoccum*, tetraploid, AABB genomes), and spelt (*T. aestivum* subsp. *spelta* (L.) Thell, hexaploid, AABBDD genomes). Spelt, emmer, and most forms of einkorn differ from bread and durum wheats in being hulled, that is, the glumes remain tightly closed over the grain and are not removed by threshing [3].

Wheat is the most important source of carbohydrate in a majority of countries, and, globally, it is the leading source of vegetal protein in human food, having a protein content of about 13%, which is relatively high compared to other major cereals. Wheat, eaten as a whole grain, is also a source of micronutrients and dietary fibre, it contains minerals, vitamins and fats (lipids), and with a small amount of animal or legume protein added is highly nutritious [3–5]. A predominately wheat-based diet is higher in fibre than a meat-based diet [6]. It is noteworthy that many health claims approved by EFSA relate to fibre components in cereals, including wheat and barley and in their positive effects on intestinal function, glucose responses, or cholesterol control [7]. The most detailed study about the significance of wheat nutrition was carried out as part of EU Framework 6 in the HEALTHGRAIN programme [8].

Doughs produced from bread wheat flour differ from those made from other cereals in their unique viscoelastic properties [9]. The raised bread loaf is possible because the wheat kernel contains gluten, an elastic ensemble of proteins that traps minute bubbles of carbon dioxide when fermentation occurs in leavened dough, causing the dough to rise [10]. Regarding human health, the gluten polymer is related to coeliac disease, a chronic inflammation of the bowel that leads to malabsorption of nutrients, estimated to affect 1% of Western Europe’s population [11]. Other diseases related to wheat have been described, such as respiratory and food allergies, which have promoted a lot of wheat research in the area of human health.

The consumption of wheat is increasing globally, even in countries with climates unfavourable for wheat production. But wheat is also a popular source of animal feed, particularly in years where harvests are adversely affected by rain and significant quantities of the grain are unsuitable for consumption. Such low-quality grain is often used by industry to make adhesives, paper additives, and several other products, even alcohol [1].

Barley (*Hordeum vulgare* ssp. *vulgare* L. $2n = 14$, diploid, HH genomes) is among the world’s earliest domesticated crop species, being cultivated in the Nile River Valley of Egypt at least 17,000 years ago [12,13]. A post-domestication change resulted in the presence of a naked cariopsis. The mutation that resulted in this change is thought to have occurred in the Middle East around 8000 BC but gradually spread to other regions so that hullless (naked) barley grains have been found in archaeological digs in Northern Scotland [14,15]. Barley was viewed as a nutritious food and Roman gladiators were known as *hordearii* (barley men) because it formed part of their training diet. Wheat gradually replaced barley as a major food cereal due to the increased numbers of grains per ear and free threshing [16].

Currently, barley is the fourth most important cereal crop in the world, grown in more than 100 countries. In the last decade, Europe has produced around 60% of the world tonnage of barley, with Asia and the Americas producing 15% and 13%, respectively [17]. Barley has a haploid genome size of ~5.3 Gb distributed over seven chromosomes. Due to its simple inbreeding diploid genetics, barley is an excellent experimental model for other temperate cereals, such as wheat, which have much bigger (17 Gb) and more complex polyploid genomes. Barley shows a good level of adaptability to unfavourable environments like cold, drought, or poor soils, and is considered more tolerant than wheat to adverse growing conditions [18].

Barley grains are mainly used for animal feed and in the production of alcoholic beverages. While feed is the main use of the barley crop, the malting barley crop is far more valuable, i.e., farmers generally receive a significant premium when selling their barley harvests to the malting market. Barley has been associated with beer production for a very long time. Traces of beer products can be

found in pottery dated back at least 9000 years and brewing is thought to have existed on an organized scale in pre-Dynastic Egypt 7000 to 5000 years ago. By 2014, world beer consumption had grown to over 1960 million hectolitres, equating to over 21.5 million tonnes of malt, at an average conversion rate of 11 kg malt to 1 hectolitre of beer [19]. Similarly, Scottish distillers, the major users of barley in the distilling segment, have increased production of malt whisky over the same period [20].

The current interest in wheat research is supported by the establishment in 2011, under the aegis of the G20 Ministries of Agriculture, of the Wheat Initiative [21]. This initiative was created for coordinating international research efforts on wheat to address the challenges raised by the fact that in recent years, wheat production levels have not satisfied demand, triggering price instability, hunger riots, and government instability. With a predicted world population of over 9 billion by 2050 [22], the demand for wheat will increase by 60% compared with 2010. To meet this demand, global annual yield increases must rise from the current 1% per year (2001–2010) to 1.6% per year (2011–2050). In the case of barley, researchers, growers, processors and producers have supported the creation of the International Barley Hub [16], a world-leading centre with the aim to translate excellence in barley research and innovation into economic, social and environmental benefits.

Global food security, threatened by climate change and an increasing population, is one of the most important challenges in the 21st century, which has to be addressed while coping with an already stressed environment [23]. Given their major role in human and animal feed, wheat and barley production must increase but in a sustainable manner. This can be addressed through either the implementation of soil and crop management practices reducing the environmental impact of agroecosystems or by the genetic improvement of crop cultivars [24]. No-till or minimum tillage strategies, organic agriculture, intercropping and cover crops, smart fertilizers, drip irrigation and fertigation are all among the agronomic practices whose suitability to replace past agricultural intensification methods is being assessed [24–26]. Regarding plant improvement, the creation of more resilient varieties capable of achieving higher yields with less input requirements (water, fertilizers, etc.) has become a primary objective of cereal breeders. A better knowledge of the genetic basis of crop performance, especially under restricted or unfavourable conditions, is needed for the success of coming breeding programs. With that in mind, current projects worldwide are focused on understanding the molecular mechanisms involved in water and nitrogen uptake, assimilation, and utilization by cereals as key plant processes in crop sustainability [27,28]. Clearly, the use of modern biotechnology techniques will be required to develop such next-generation varieties. The availability, since 2012, of a barley genome reference sequence has allowed the earlier development of genomic tools in barley than in wheat, whose first high-quality reference sequence was not published until 2018 [29,30]. Understanding and exploiting the genetic diversity pooled in large collections of germplasm available for both species will be highly helpful for gene discovery and genome-assisted crop improvement [31–33].

The recent development of scientometrics [34,35], informetrics [36] and bibliometrics [37,38] has allowed the study of scientific trends in specific fields. In turn, these analytical techniques of scientific production are necessary for the assessment of the current state of research, as well as the contributions of researchers and countries in the fields of knowledge [37]. Furthermore, bibliometric indicators that measure the results of the scientific production in a specific field by a country or organization can also be considered as the economic and social indicators because a large amount of resources are invested in it [39]. Therefore, the aim of this work was to comparatively assess the historical evolution and current trends of research on wheat and barley by performing a descriptive and retrospective bibliometric study on the worldwide scientific production on these two major crops. An earlier study indicated that the journal coverage is higher in Scopus than in Web of Science [40]. In addition, numerous research articles have suggested the advantages of using Scopus to implement a bibliometric analysis [41,42]. Therefore, the Scopus database was selected. Given that massive information downloads are not possible from other databases such as PubMed, these databases are not useful to carry out bibliometric studies [43].

2. Methods

The research documents and patents analysed in this work were extracted from the Elsevier Scopus database. The search queries (TITLE-ABS-KEY({Wheat})) and (TITLE-ABS-KEY({Barley})) were used in January 2019 for collecting academic documents and patents including “wheat” or “barley” terms in the title, abstract and/or keywords.

The articles from the search were assessed and classified according to diverse aspects: number of documents per year, document type and language, distribution by subject categories and by journals, and affiliation by country and institution. The records obtained were analysed and the results were used to make graphs with the aim to display the results more conveniently.

The list of the 160 most abundant keywords in the documents retrieved, provided by the Scopus database after any search, was further analysed qualitatively and quantitatively. The terms listed were manually classified into four relevant thematic groups. The list provided after the initial search (i.e., main keywords considering all scientific documents dated up to 2018) was used to conduct the analysis of keywords related to cereals-and-model-plants and human-and-animals. In the case of terms related to agronomy and genes-and-proteins, two lists of keywords corresponding to the documents dated up to 1999 and from 2000 to 2018, were analysed for each crop. For conducting a more informative assessment on the relative importance of specific terms within the thematic clusters, duplicated words (e.g., singular and plural of a term) or synonymous terms (e.g., “chromosomes, plant” and “plant chromosome”) were fused as one keyword. The whole sets and the clusters of keywords were used to obtain word clouds from the free software WordArt (<https://wordart.com/>). In these clouds, font size of a given keyword represents the number of times it appears in literature records.

3. Results and Discussion

3.1. Evolution of Scientific Output and Distribution by Countries, Institutions, and Languages

The term “wheat” has been detected in the title, abstract or keywords of a total of 169,297 documents over the period 1835–2018, while “barley” has been identified in 50,140 articles from 1833. The number of studies dealing with “wheat” and “barley” has grown in a continuous way since the first publication. A remarkable increase in publications was noted for both research topics since the second half of the twentieth century (Figure 1).

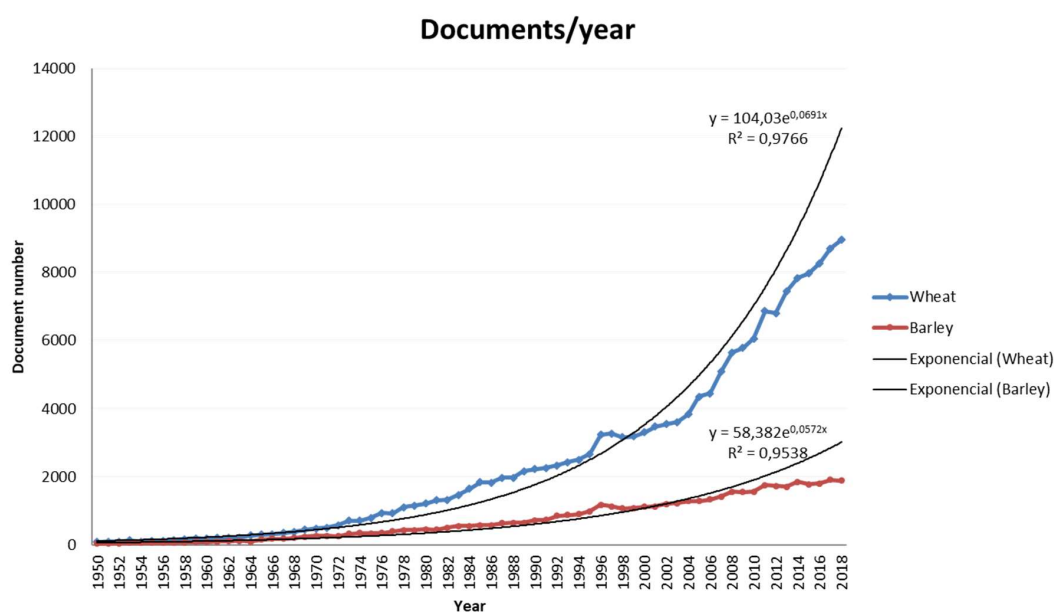


Figure 1. Trends in publications on Wheat and Barley research fields.

The significant rise of academic reports about wheat and barley in recent years could represent the general increase of scientific publications, rather than a real growing interest of the scientific community in these crops. In order to explore the former possibility, a further analysis was conducted, limited to the documents published in English. Therefore, the ratio of documents dated up to 1999 and from 2000 to 2018 was calculated for total publications, and for publications including wheat or barley in the title, abstract and/or keywords. The results pointed out that the increment experienced for publications on wheat (ratio 1:1.94) is actually higher than the observed when the global scientific production is considered (ratio 1:1.66). On the contrary, the ratio obtained for barley (1:1.40) is below the average, at least within English documents. Articles related to wheat have outnumbered those related to barley every year since the earliest reports. A different trend on the evolution of the scientific interest in both crops can also explain that the differences are enlarging at a higher rate since 2004 (Figure 1). These metrics surely reflect either the greater agro-economic relevance of wheat, with a worldwide production 5-fold higher than that of barley (772 and 147 million tonnes of wheat and barley, respectively, in 2017; data from FAOSTAT, Jan 21, 2019), and the increasing concerns about crops used for human consumption.

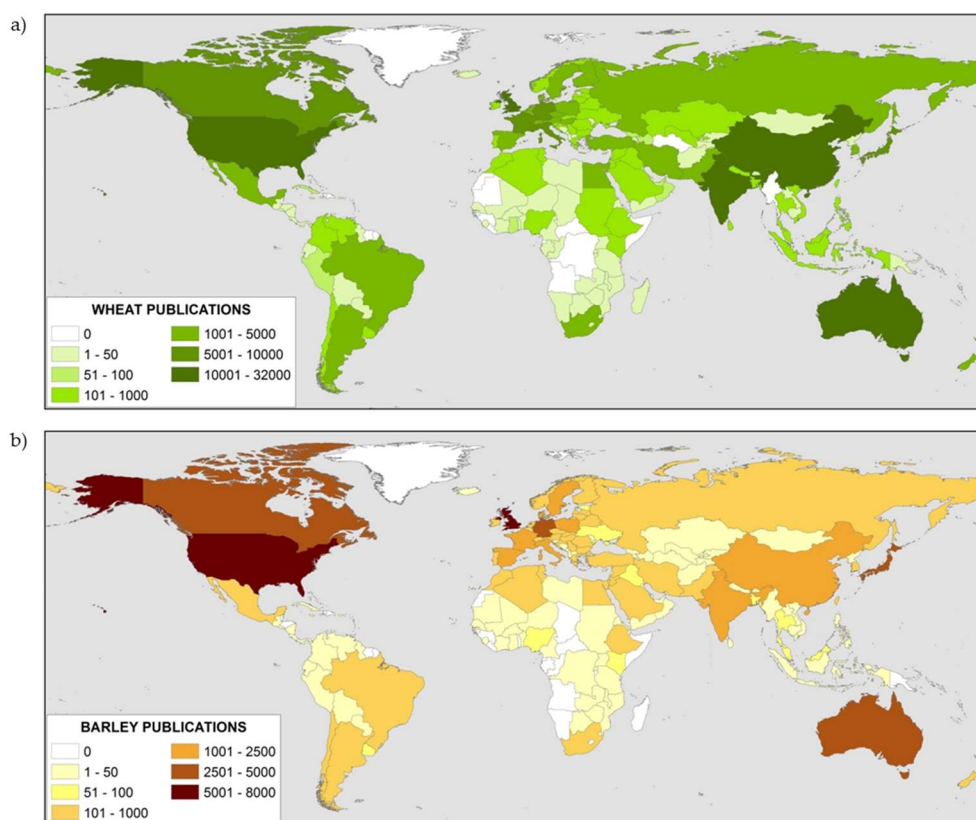


Figure 2. Worldwide research on wheat (a) and barley (b) up to 2018.

However, the interest in wheat or barley research is not equally represented among countries. Wheat and barley have been the focus of research in 159 and 158 countries, respectively, again proving the worldwide relevance of these crops. Twenty-one countries contributed more than 1% of the scientific reports related to wheat and barley (Table 1). These countries together published about 77% of the total documents dealing with wheat (77.01%) and barley (77.28%). However, our results showed remarkable differences in the relative contribution of some countries to studies on each of these crops (Table 1, Figure 2). For instance, countries such as USA, China, India, France, Pakistan, Brazil and Mexico contribute more to wheat than barley research, while the opposite is observed for UK, Canada, Germany, Spain, Sweden, Denmark, Czech Republic and Finland. These results agree with FAO information about wheat and barley production by continents and countries [17]. According

to this source, wheat and barley are mainly produced in Asia and in Europe, respectively (Figure 3a,c). The top ten list of wheat producers is headed by China and India (Figure 3b), which are not included in the list of main barley producers, where European countries, such as Germany, France and Spain, are, however, included (Figure 3d). It should be noted that several of the countries highly represented in wheat research are developing countries where wheat is one of the nutritional staples (e.g., China, India, Pakistan, Brazil and Mexico; Table 1). On the other hand, countries more interested in barley research are developed countries, mainly in Europe (UK, Canada, Germany, Spain, Sweden, Denmark, Czech Republic and Finland; Table 1), where the ecoclimatic conditions are more suitable for this cereal crop [44]. The fact that barley is essential for the production of beer, among the most popular beverages in Europe, may point to the influence of some particular socio-cultural habits on the scientific interests of each country.

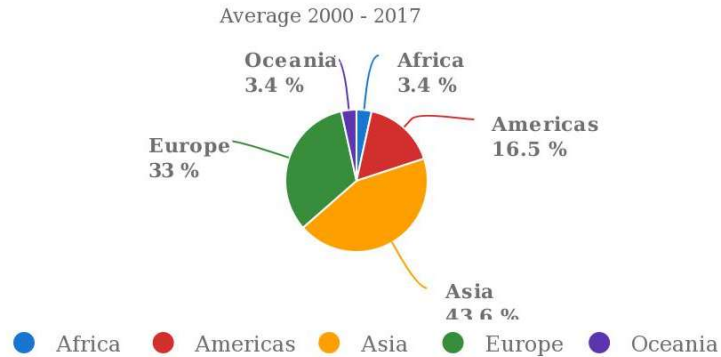
Table 1. Scientific production by countries measured by the absolute number (N) and the relative contribution (%) of documents in the wheat and barley research fields. Their position in a ranking according to number of documents published is also indicated.

Wheat				Barley			
Position	COUNTRY	N	%	Position	COUNTRY	N	%
1	United States	31899	15.40	1	United States	7646	12.20
2	China	21888	10.57	2	United Kingdom	6646	10.60
3	India	12845	6.20	3	Germany	4262	6.80
4	United Kingdom	12075	5.83	4	Canada	4060	6.48
5	Australia	10737	5.18	5	Australia	3346	5.34
6	Canada	8913	4.30	6	Japan	2779	4.43
7	Germany	8746	4.22	7	China	2373	3.78
8	Japan	7808	3.77	8	Denmark	2333	3.72
9	France	6398	3.09	9	Spain	1992	3.18
10	Italy	5292	2.56	10	India	1500	2.39
11	Spain	4102	1.98	11	Sweden	1485	2.37
12	Pakistan	3475	1.68	12	Italy	1341	2.14
13	Iran	3405	1.64	13	France	1303	2.08
14	Brazil	3142	1.52	14	Poland	1267	2.02
15	Poland	3135	1.51	15	Iran	993	1.58
16	Turkey	2927	1.41	16	Finland	967	1.54
17	Netherlands	2881	1.39	17	Czech Republic	957	1.53
18	Russian Federation	2838	1.37	18	Netherlands	903	1.44
19	Sweden	2576	1.24	19	Russian Federation	846	1.35
20	Mexico	2258	1.09	20	Turkey	744	1.19
21	Denmark	2258	1.04	21	South Korea	711	1.13
26	Czech Republic	1660	0.80	28	Brazil	451	0.72
29	South Korea	1421	0.69	35	Mexico	313	0.50
30	Finland	1303	0.63	38	Pakistan	259	0.41

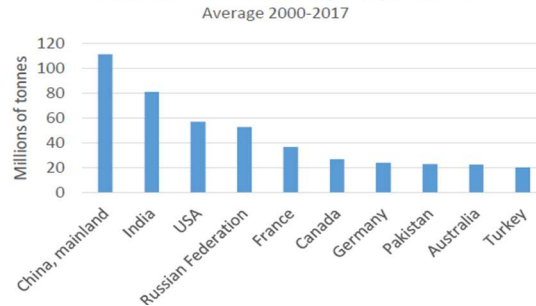
The 20 most productive institutions studying wheat and barley in the period are analysed in Table 2. As expected according to the results mentioned above, the institutions with the highest numbers of publications related to wheat were from the US (4 institutions), China (7), Canada (2), France (1), UK (1), India (2), Netherlands (1) and Australia (1), while the corresponding institutions for barley publications were from Canada (4), US (4), Sweden (1), UK (1), Germany (1), Australia (2), Scotland (1), France (1), Denmark (4) and Netherlands (1). In the top twenty most productive research centres, ten institutions from the US, Canada, UK, Australia, France and Netherlands were on both the wheat and barley lists. The remaining institutions again reflect the marked differences in the countries' research interest in these crops (Table 2). Nine out of the 20 top institutions leading wheat research are agroalimentary and agricultural research centres from developing countries, such as China and India, while agricultural centres placed in Europe (e.g., Sweden, UK, Germany, France, Scotland, Netherlands and Denmark) are among the most relevant in barley research. It should be noted that in 13th position

is the Carlsberg Research Centre from Denmark, which is exclusively focused in the art of brewing (<https://carlsberggroup.com/who-we-are/groundbreaking-research/>).

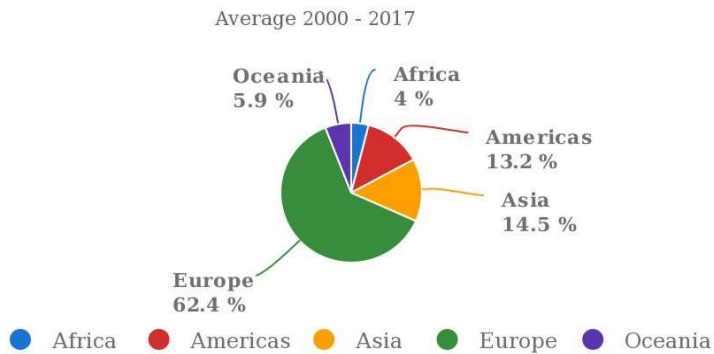
(a) Production share of Wheat by region



(b) Production of Wheat: Top 10 producers



(c) Production share of Barley by region



(d) Production of Barley: Top 10 producers

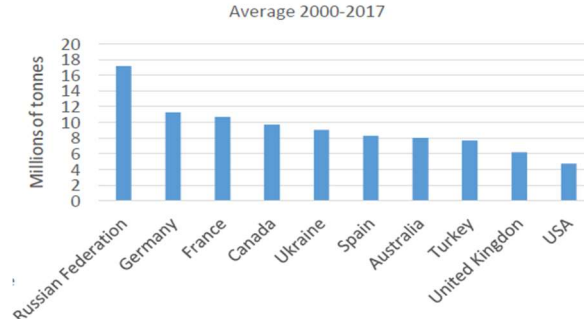


Figure 3. Wheat (a,b) and barley (c,d) production by regions (a,c) and by countries (b,d). Source: FAOSTAT.

Table 2. Rankings of the 20 most productive institutions in the wheat and barley research fields. Institutions included in both lists are in bold lettering.

Wheat			Barley		
Affiliation	Country	N	Affiliation	Country	N
USDA Agricultural Research Service, Washington DC *	USA	4798	Agriculture et Agroalimentaire Canada *	Canada	1695
Chinese Academy of Sciences	China	4107	USDA Agricultural Research Service, Washington DC *	USA	1184
Agriculture et Agroalimentaire Canada *	Canada	3355	United States Department of Agriculture *	USA	794
United States Department of Agriculture *	USA	3260	Sveriges lantbruksuniversitet *	Sweden	754
INRA Institut National de La Recherche Agronomique *	France	3152	Rothamsted Research *	UK	739
Chinese Academy of Agricultural Sciences *	China	2231	Leibniz Institute of Plant Genetics and Crop Plant Research *	Germany	705
Kansas State University	USA	2129	The University of Adelaide	Australia	678
China Agricultural University *	China	2088	University of Saskatchewan	Canada	628
Northwest A&F University *	China	1764	The James Hutton Institute *	Scotland	621
Rothamsted Research *	UK	1750	University of Alberta	Canada	602
Indian Agricultural Research Institute *	India	1708	INRA Institut National de La Recherche Agronomique *	France	592
Wageningen University and Research Centre *	Netherlands	1564	Danmarks Tekniske Universitet	Denmark	573
Ministry of Agriculture of the People's Republic of China *	China	1497	Wageningen University and Research Centre *	Netherlands	531
CSIRO Plant Industry *	Australia	1367	Carlsberg Research Center	Denmark	527
Washington State University Pullman	USA	1334	University of Copenhagen Faculty of Life Sciences *	Denmark	484
Ministry of Education, China	China	1292	Københavns Universitet	Denmark	481
The University of Adelaide	Australia	1274	Washington State University Pullman	USA	465
Punjab Agricultural University, India *	India	1251	CSIRO Plant Industry *	Australia	458
Nanjing Agricultural University *	China	1235	University of California, Davis	USA	401
University of Saskatchewan	Canada	1208	University of Manitoba	Canada	389

* Research Institutions focused on Agronomy. N: Number of scientific documents published by affiliation.

Research studies on wheat and barley have been published in 43 and 35 different languages, respectively. As expected, because English is the international language of science and technology, this was the most used language to publish wheat (156,596 reports, which account for 91.52%) and barley documents (47,785 reports, which account for 94.42%) (Figure 4). In studies related to wheat, English is followed by Chinese (with a mere 3.17%), in accordance with the fact that China has published the second highest number of documents on wheat (Table 1). However, in studies related to barley, English is followed by German (1.5%), which also agrees with the fact that Germany was the country that published the third highest barley reports, behind two English-speaking countries (the US and UK, Table 1). It can be noted that wheat papers published in Chinese are six times more frequent than Chinese barley documents, which indicates again the higher interest of developing countries like China in wheat than in barley.

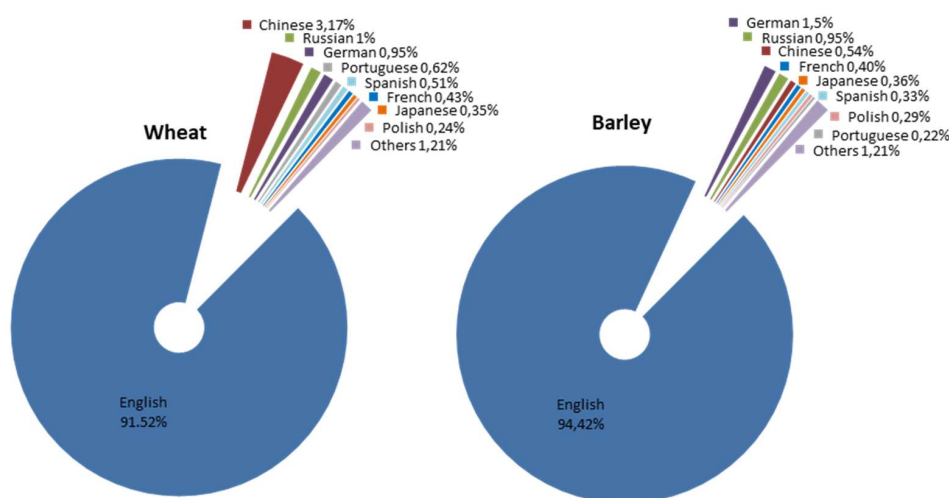


Figure 4. Languages of scientific output in the wheat and barley research fields.

3.2. Subject Categories, Sources and Types of Publications

Publications on wheat research are distributed across 29 subject areas according to the Scopus classification. The largest number of documents is included in the agricultural and biological science area (102,629 records, 36.72%), followed by biochemistry, genetics and molecular biology (51,332 records, 18.36%), environmental sciences (20,517 records, 7.34%), medicine (19,220 records, 6.88%), chemistry (13,204 records, 4.72%), immunology and microbiology (10,315 records, 3.69%), engineering (10,056, 3.60%), earth and planetary sciences (7338, 2.63%) and chemical engineering (7084, 2.53%). Almost 90% of wheat publications are included in these nine areas (Figure 5). It must be noted that a single document can be assigned to more than one area.

Barley scientific documents are also distributed across 29 subjects. Eight of the top nine areas for barley are also among the most important areas for wheat research. Agricultural and biological science (34,714 records, 42.12%) is again the first area, and biochemistry, genetics and molecular biology the second (19,448 records, 23.60%). The third area is environmental sciences (4534 records, 5.50%), the fourth medicine (4492 records, 5.45%) and the fifth is chemistry (3123 records, 3.79%). The sixth area is immunology and microbiology (2,981 records, 3.62%), followed by veterinary (1717, 2.08%), earth and planetary sciences (1539, 1.87%) and engineering (1519, 1.84%). These nine areas account for 90% of barley publications (Figure 5).

As expected, results showed that research documents on wheat and barley are mostly published under the same categories and in a rather similar percentage. The only remarkable difference was the incorporation of the veterinary category among the top positions in barley, an area that has no relevance for wheat (Figure 5). This finding is in agreement with the high percentage of barley production that is used for animal feeding [44].

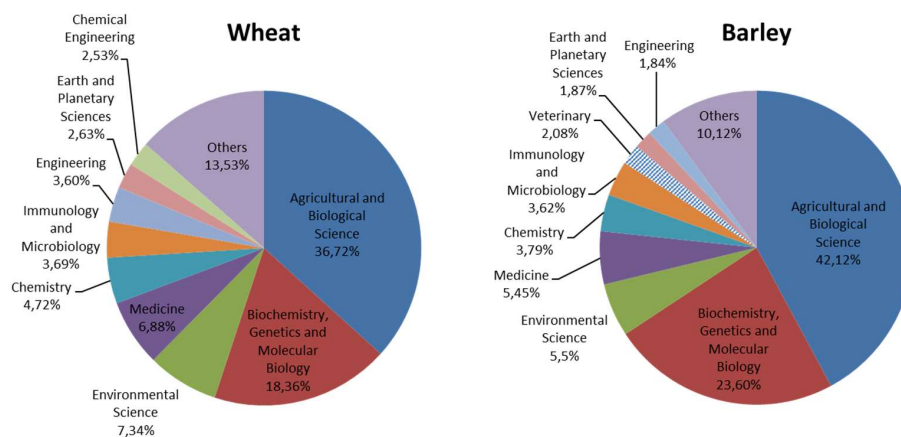


Figure 5. Distribution (%) of worldwide research on wheat and barley by subject area, as classified by Scopus.

Regarding the number of publications by source, Table 3 lists the top 10 journals in which results from the wheat and barley research fields have been published in. Both lists only shared three journals, i.e., *Theoretical and Applied Genetics*, *Euphytica*, and *Plant and Soil*, which publish articles “with a clear genetic component and significant impact on plant breeding”, “modern and traditional plant breeding using transgenic crop plants and/or marker assisted breeding in combination with traditional breeding tools” and “plant–soil interactions”, respectively. The remaining journals with a high number of wheat publications are quite specific for cereals, crops and food. However, journals where barley documents are mainly published are journals whose scope includes varied aspects of plant biology. As significant exceptions, the first journal where barley research studies are found, *Journal of the Institute of Brewing*, publishes documents relating to brewing, fermentation, distilling, raw materials and by-products, and the third in the list, *Animal Feed Science and Technology*, is a unique journal publishing scientific papers of international interest focused on animal feeding. These journals cover the two main applications for barley: brewery and animal feed production.

Table 3. Top 10 sources of publications in the wheat and barley research fields. Journals included in both lists are in bold lettering.

Wheat		Barley	
Source Title *	N	Source Title	N
Theoretical And Applied Genetics (2)	2048	Journal Of The Institute Of Brewing	897
Journal Of Cereal Science (15)	1762	Theoretical And Applied Genetics	771
Journal Of Agricultural And Food Chemistry (12)	1734	Animal Feed Science And Technology	669
Euphytica (9)	1715	Plant Physiology	577
Plant And Soil (7)	1370	Journal Of Agricultural Science	564
Cereal Research Communications (36)	1303	Journal Of Experimental Botany	561
Cereal Chemistry (43)	1273	Plant And Soil	540
Journal Of The Science Of Food And Agriculture (11)	1249	Planta	517
Field Crops Research (45)	1212	Euphytica	501
Crop Science (25)	1209	Physiologia Plantarum	476

* Numbers in brackets indicate the journal position in the barley list. N: Number of scientific document published in each source.

The scientific documents about wheat or barley recovered from the Scopus database were classified into 15 document types. The four types with a percentage higher than 1% are “article”, “conference paper”, “review” and “book chapter” (Table 4).

Table 4. Distribution of document types for research on wheat and barley.

DOCUMENT TYPE	Wheat		Barley	
	N *	%	N	%
Article	151914	89.73	45695	91.13
Conference Paper	7229	4.27	1387	2.77
Review	4388	2.59	1466	2.92
Book Chapter	2254	1.33	745	1.49
Book	190	0.11	50	0.10
Conference Review	174	0.10	18	0.04
Others	3148	1.86	779	1.55

* N: Number of scientific documents in each category. %: percentage of documents published in each category.

“Article”, which accounted for 89.73% of total publications with 151,914 reports for wheat and 91.13% with 45,695 for barley, was the most common document type to publish results from the wheat and barley research fields. In second place, “conference paper” accounted for 4.27% with 7,229 reports on wheat and 2.77% with 1,387 on barley, followed by “review” with 4,388 reports on wheat (2.59%) and 1,466 documents (2.92%) on barley, as well as “book chapter” with 2,254 documents on wheat (1.33%) and 745 documents on barley (1.49%). These four document types accounted for 97.93% and 98.31% of total publications on wheat and barley respectively. Globally, the remaining types of documents, “book”, “conference review”, “note”, “letter”, “erratum”, “short survey”, “editorial”, “business article”, “report”, “retracted”, and “undefined” accounted for 2.07% and 1.69% of total publications, individually contributing between 0.003–0.46% for wheat and between 0.002–0.41% for barley (Table 4). The results prove that articles are preferentially used by most authors to publish their scientific findings in these fields.

3.3. Keywords

The main research subjects in a given manuscript are summarised by the keywords defined in it. Thus, the assessment of the keywords of scientific documents allows for the establishment of the research trends in a specific field [45]. A word cloud made with all 160 keywords that the Scopus database showed for the articles related to wheat or barley, analysed in the present report, are shown in Figure 6. As expected, “*Triticum aestivum*” and “*Triticum*” are the two keywords most represented in wheat documents, which is the taxonomic nomenclature of bread wheat, the most relevant wheat crop species (Figure 6a). Similarly, the keyword most used in the documents from barley research is “*Hordeum*”, the genus that includes cultivated barley, whose species name (*Hordeum vulgare*) is actually fourth among the keywords in barley documents (Figure 6b). The second and the sixth barley-related keywords most employed are “*Triticum aestivum*” and “wheat” respectively, showing the important relation between both crops, and that wheat is frequently used as a reference for discussion of barley research results. In both lists, “maize” is the most frequent keyword of a plant species other than wheat and barley. Its relevance in wheat and barley documents is surely related to the fact that maize is not only cultivated for human and animal consumption but is also the most produced crop worldwide. Furthermore, the maize genome was sequenced in 2009 and has been commonly used as a reference in barley and wheat genomics [46]. The keywords “human”, “animal” and “nonhuman” are quite abundant in documents related to either wheat or barley. However, while “nonhuman” and “animal” show similar frequency in both sets of documents, “human” shows a more relevant position in wheat than in barley documents. This is surely ascribable to the distinct primary uses of wheat and barley grains. “Genetics” appears as the most relevant among the scientific disciplines, which likely shows the pivotal role that the studies on heredity and variation of plant traits have always had on crop research. “Chemistry” is also a relevant discipline that might reflect the importance of grain composition on its nutritional quality and on the rheological properties of flour doughs in the case of wheat [47].

A deeper study has allowed us to organize the keywords into thematic groups. We could separate keywords into four clusters: related cereals and model plants, human and animals, agronomy, and genes and proteins (Figures 7–9).

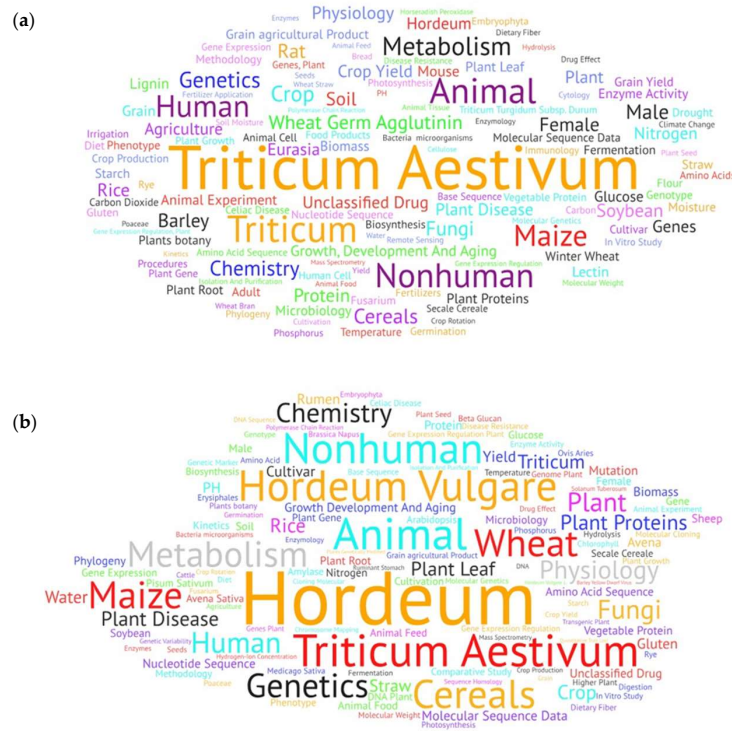


Figure 6. Word cloud based on the main keywords related to wheat (a) and barley (b) in worldwide research.

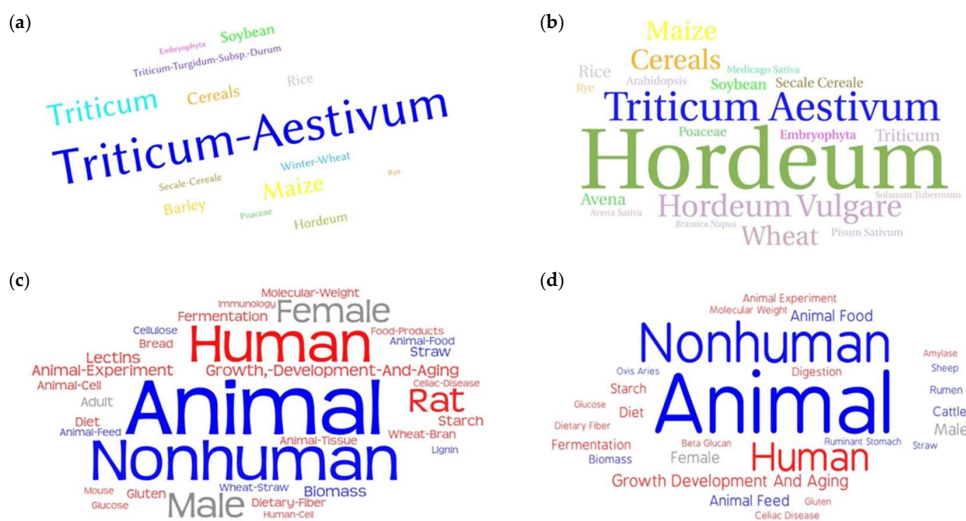


Figure 7. Word cloud based on the main keywords related to cereals and model plants (a,b), and human and animals (c,d), in wheat (a,c) and barley (b,d) research documents.

When the keywords noting plant species were metricized, results showed that barley documents included more varied plant species. Wheat is mainly associated with other “cereals”, such as “maize”, “barley”, “rye”, “rice”, etc. (Figure 7a), whereas barley is not only related to numerous cereals but also with many model species, such as “*Arabidopsis*”, “*Brassica napus*”, “*Medicago sativa*” and “*Solanum tuberosum*” (Figure 7b). This can be due to the fact that barley is considered a model species for temperate cereals and so it is frequently contrasted with other model plants [48]. Regarding the cluster grouping human and animal keywords, wheat is associated with numerous terms related to human food or health, such as “diet”, “gluten”, “glucose”, “dietary fibre”, “bread”, “flour”, “celiac disease”, “immunology”, “wheat-bran”, etc. (Figure 7c), while barley is principally associated with terms

related to livestock animals such as “sheep”, “rumen”, “cattle”, “ruminant stomach”, “ovis aries”, etc. (Figure 7d). These results again indicate the distinct main use of wheat and barley production for human food and animal feed, respectively. In addition, wheat documents show more keywords related to biofuels, such as “lignin”, “cellulose” and “biomass”, than barley reports (Figure 7c,d), suggesting a higher interest in wheat than barley as a biofuel. However, this trend could change in the near future because barley is currently being studied as a promising biofuel source [49].

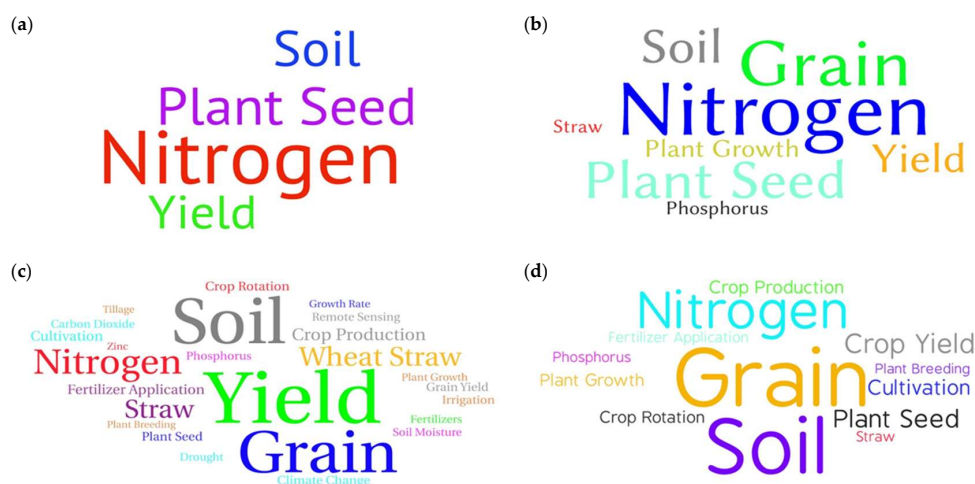


Figure 8. (a–d) Word cloud based on the main keywords related to agronomy in worldwide research until 1999 (a,b) and from 2000 (c,d) in wheat (a,c) and barley (b,d).

For keywords clustered into the agronomy and genes and proteins thematic groups, documents dated up to 1999 and from 2000 to 2018 were separately considered. This analysis showed that, among the more frequent keywords listed in the Scopus database, the number of terms related to agronomy markedly increased over the period 2000–2018 compared to the earlier period for either of these crops. In the case of wheat, documents up to 1999 included only basic terms, such as “nitrogen”, “soil” or “yield”, whereas more recent documents included up to 25 keywords (Figure 8). Most of these novel keywords refer to environmental issues impacting crop production or to soil–crop management and monitoring innovations, some of which are being explored in the context of cropping sustainability, i.e., “fertilizer application”, “crop rotation”, “climate change”, “irrigation”, “remote sensing”, “carbon dioxide”, “soil moisture”, “drought” or “tillage”. Far fewer novelties were detected among the main keywords used in recent barley documents, “crop rotation” and “fertilizer application” being the only innovative terms. This shows a much greater concern for the negative impact of environmental constraints on wheat crops and the prominence of wheat in the implementation of sustainable agroecosystem practices [24,26], which is in close correspondence with its larger cultivated area, higher production and socio-economic relevance compared to barley [50].

Our analysis also showed a higher number of terms related to genetic and molecular topics in the period 2000–2018 compared to the earlier period (21 versus 14 in “wheat” documents; 30 versus 24 in “barley” documents). The finding that, at any period, barley is connected with more keywords from this group than wheat is likely attributable to two different factors: (i) much more varied scientific topics have interested wheat researchers, which is reflected in the many keywords listed in the Scopus database that are related to other scientific disciplines; and (ii) molecular and reverse genetic approaches are more straight-forward in barley compared to wheat [48]. Our results have clearly demonstrated the different timelines of the progression of knowledge on wheat and barley in the affected disciplines (i.e., genetics and molecular biology). Up to 1999, most keywords in wheat mainly referred to molecules involved in genetic processes and their structure (Figure 9a). By contrast, “molecular cloning”, “mutation”, “gene expression” and “gene expression regulation” were already key terms in that earlier barley-related research (Figure 9b). It is significant that the keyword “molecular

genetics” was found in a quite similar number of documents in the wheat and barley keyword lists (486 and 337, respectively) despite three-times more documents mentioned wheat than barley in that period (57,376 versus 21,060). In scientific documents published between 2000 and 2018, terms like “gene expression” and “gene expression regulation” have come to enter the wheat-related keywords list, which also includes, as remarkable novel terms, “chromosome mapping”, “genetic variability” and “genetic marker” among others (Figure 9c). Nevertheless, it seems again evident that the application of molecular tools has progressed much more quickly in barley, whose 2000–2018 list of main keywords includes, for instance, “quantitative trait loci” and “transgenic plant” (Figure 9d).

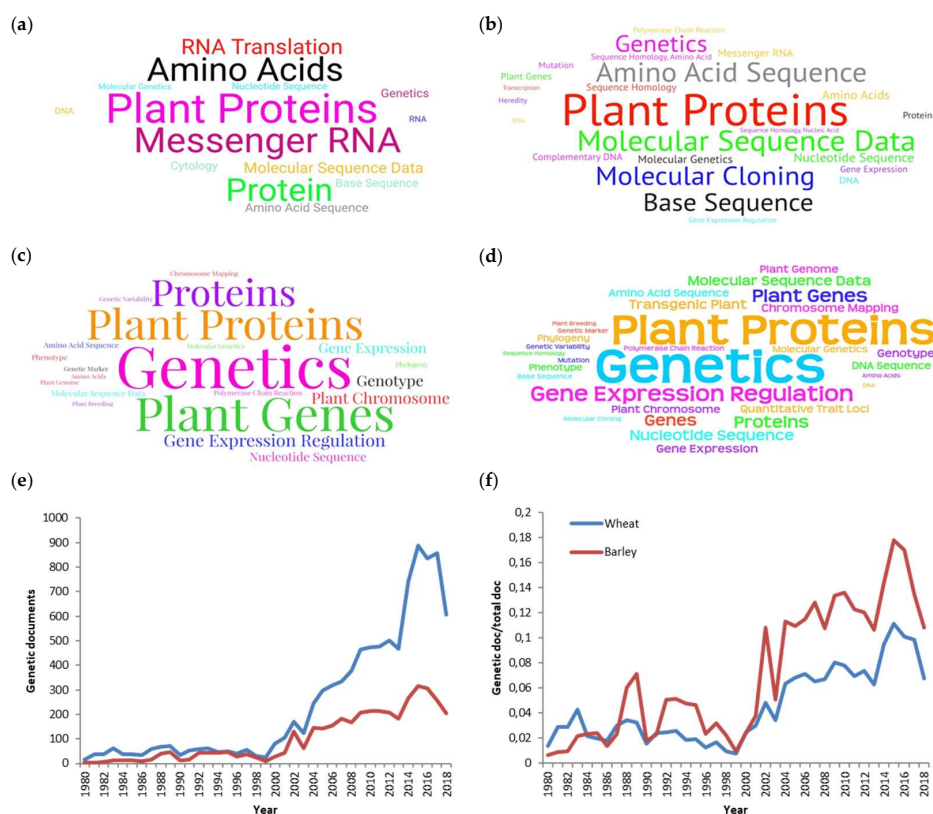


Figure 9. (a–d) Word cloud based on the main keywords related to genes and proteins in wheat (a,c) and barley (b,d) in worldwide research until (a,b) and from (c,d) the year 2000. (e) Number of genetics-related documents by year in the wheat and barley research fields. (f) Number of genetics-related documents with respect to the total number of scientific document in the wheat and barley research fields.

This idea is also supported by the number of documents related to genetics in absolute or relative terms for each crop. We evaluated the temporal distribution of the keyword “genetics” in wheat and barley publications. Results showed that both evolution lines followed similar patterns, although the number of genetics-related documents in wheat research increased more quickly than in barley from the year 2000 (Figure 9e). However, when these absolute numbers were relativized to the global volume of wheat and barley documents, the tendency lines changed. The ratio is higher for barley than for wheat since the 1980s, but especially from 2004 (Figure 9f). This again suggests that the use of reverse genetics is more common in barley than in wheat research. This is likely due to the fact that, although both species possess large genomes characterized by a high content of repetitive elements and large pericentromeric regions that are virtually devoid of meiotic recombination, the barley genome is diploid, while wheat varieties possess a tetra- or hexaploid genome. This has facilitated sequence of barley genome before the wheat genome (2012 versus 2018), giving barley a clear advantage over wheat for performing reverse genetics, analyzing the role of specific genes, and other numerous improvements [48].

3.4. Patents

The number of documents published on a specific research topic gives an idea about its scientific relevance. On the contrary, patent metrics allow to assess the industrial interest in that particular issue.

The temporal progressions of the number of patents related to wheat and barley have followed similar patterns (Figure 10a). Nevertheless, the counts for barley are always two to three times lower than for wheat, as already noted regarding scientific documents (see Figure 1). However, when the number of patents is weighted with respect to the number of documents published, a noticeable change is observed (Figure 10b). Until the 1970s, the ratio between the number of patents and documents was higher in wheat than in barley suggesting a higher scientific and industrial interest in wheat. From the 1970s to the beginning of the 21st century, the patent/scientific document ratio was similar in both crops, showing an increasing industrial interest in barley. Finally, in the last 10 years, the ratio for barley has at least doubled to that of wheat. This suggests that although the scientific community continues to maintain a greater focus on wheat, the industrial interest in barley has comparatively experienced a much higher relative increment (Figure 10b). The investment returns from innovations in malting procedures and novel beer brewing processes, including those involving the elaboration of trendy craft beers, are surely among the reasons encouraging the barley-related scientific community to protect the research outcomes suitable to be patented.

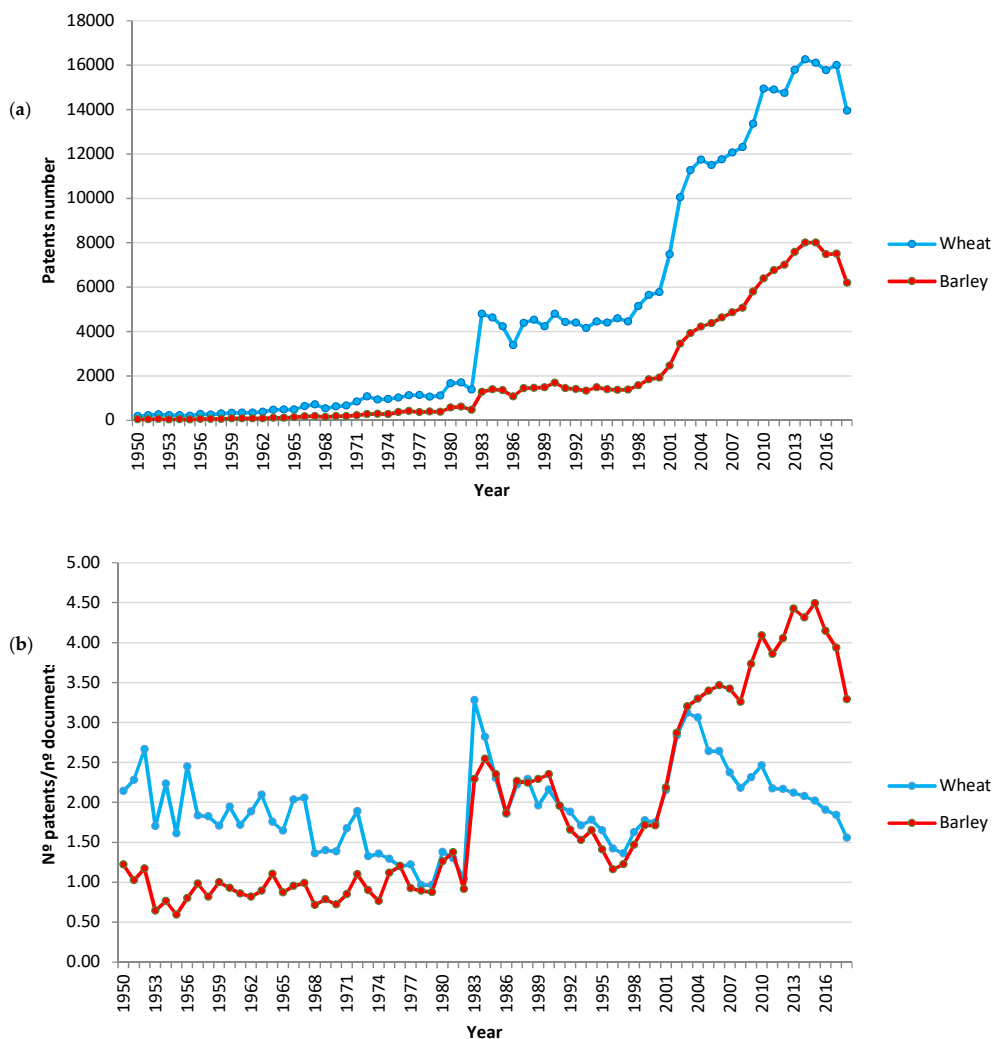


Figure 10. Trends in patents in the wheat and barley research fields. (a) Number of patents by year. (b) Ratio between patents and scientific documents.

4. Conclusions

The bibliometric assessment of scientific documents related to wheat and barley has allowed us to analyse past and current trends in wheat and barley research. Some of the differences observed between the two sets of data can be explained by the distinct major human uses of wheat (human consumption) and barley (animal feeding and brewing), the former crop being much more represented in absolute terms (i.e., number of publications and patents) in the Scopus databases at any time analyzed. As expected because of their close botanical and agronomical relationship, wheat and barley research documents share many main keywords. However, some differences, mostly related to their respective uses by humans, different agricultural and economic prevalence and genome complexity, were found when keywords were grouped in thematic clusters. Our results point out the current importance of sustainability in agroecosystems for a major crop like wheat, and an increased focus of research projects on genetics and molecular biology in barley. The latter can be attributed to the diploid condition of barley, which has experienced an earlier and much faster development of genetic and genomic resources than wheat. Similarly, the evolution of the ratio of patents/scientific documents shows an increasing industrial interest in barley when compared to the temporal tendency of the protection of research results in wheat. Finally, the differences regarding document languages and top countries in the affiliations of publications dealing with wheat and barley seem attributable to some extent to the distinct socio-economic relevance of each of these crops on a global scale.

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