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EMMER – A BYGONE AND NEWLY FOUND CEREAL: A BIBLIOMETRIC ANALYSIS (1905-2025)

SUMMARY

Emmer has recently garnered significant attention. This bibliometric study analyses a dataset from Scopus covering the period from 1905 through August 18, 2025 and including a total of 2,383 emmer-related documents. Emmer research has experienced a marked increase in both publication output and citation impact over time. Specifically, the cumulative annual percentage growth rate for the number of publications reached 893% (1982–2021), while the average annual citation count grew by 67% between 1970 and 2019. Theoretical and Applied Genetics, Euphytica and Vegetation History and Archaeobotany were found to be the top journals in terms of both number of publications and H-index. China, USA, Israel, Italy, Turkey, Germany, United Kingdom, India and Japan were identified as the most prolific countries, with Israel being the most cited one. The University of Haifa and Sichuan Agricultural University turned out to be the most productive organizations. Nevo E. and Fahima T. were both the greatest contributors and the most cited authors. The collaboration clusters were constructed for countries, institutions and authors. The theme trends and hotspots in emmer research were analysed: thus, genetics, metabolism and phylogeny were detected as Motor Themes, while archaeobotany and related cereal species were Emerging or Declining Themes. Through such structured approach, researchers can better define their problems, identify future challenges and establish collaboration links.

Keywords: *Triticum dicoccum*, *Triticum dicoccoides*, scientific output, knowledge mapping, research trends

INTRODUCTION

Ancient wheat species, i.e. einkorn, emmer and spelt, have been neglected for many years. They were widely cultivated in the ancient world, but later

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became primarily relict crops because of low yields as well as cultivation and processing difficulties. Nowadays, health issues are gaining importance and underutilised wheat species have a number of benefits for health compared to traditional bread wheat (*Triticum aestivum* L.) and pasta wheat (*Triticum durum* Desf.), so they are drawing growing attention of scientists, farmers and consumers. The increasing interest shown towards ancient wheat species is associated with the search for naturalness. Since the 1980s, health-conscious people and gourmets have started to demand ancient cereals, including emmer.

Emmer (*Triticum dicoccum* (Schuebl.) Schrank) is a tetraploid (2n=48) wheat species. Emmer was one of the first crops domesticated by humans. Wild emmer (*Triticum dicoccoides* (Schrank) Schuebl.) is the ancestor of domestic emmer. The phylogeny of wild emmer seems to be clear: it is a result of the hybridization between two diploid wild grasses, the wild red einkorn (*Triticum urartu*) and the goatgrass (*Aegilops speltoides* Tausch) (Marcussen *et al.*, 2014). Wild emmer is native to the Fertile Crescent of the Middle East. In modern times, it grows in the grasslands and woodlands of Israel and Iran. The earliest location of emmer domestication is still under debate (Weide, 2015), as several locations were suggested as the earliest sites of emmer domestication during the Early Pre-Pottery Neolithic B. The principal difference between the wild and the domestic species is that ripened spikes of the wild species shatter and spread seeds onto the ground while in the domesticated emmer spikes remain intact, thus making it easier for farmers to harvest grain (Weiss and Zohary, 2011).

Emmer is a hulled wheat species, meaning it has strong glumes that enclose its caryopses and semibrittle rachides. These traits make threshing difficult: upon threshing, emmer spikes break up into spikelets that require great efforts (milling or pounding) to release grains from glumes (Amar, 2015), so it is understandable that producers prefer more easily threshable wheats. However, this underutilized cereal has a great potential to improve nutrition, boost food security and satisfy the increasing demand for traditional products (National Research Council, 1996; Stagnari *et al.*, 2008). Currently, emmer is grown in Armenia, Morocco, Spain, Czechia, Slovakia, Albania, Turkey, Switzerland, Germany, Greece, Italy and the US.

Emmer value lies in its ability to yield a lot in aridity (Krugman *et al.*, 2011; Kuzuoglu-Ozturk *et al.*, 2012; Suneja *et al.*, 2015), in heat (Ullah *et al.*, 2021; Yousif *et al.*, 2022) and on poor soils (Giuliani *et al.*, 2009). Emmer is also noticeable for resistance to fungal diseases (Piarulli *et al.*, 2012; Sharma *et al.*, 2019; Tene *et al.*, 2022; Lhamo *et al.*, 2023) and pests (Liu *et al.*, 2005). Hence, emmer can be successfully grown in organic farming even in areas with lower production potentials (Kovács, 2008; Emődi *et al.*, 2014).

Emmer is considered a healthy food due to increased contents of protein (Osokina *et al.*, 2020; Zaparenko *et al.*, 2020), carotenoids (Somma *et al.*, 2004; Marconi and Cubadda, 2005; Holik *et al.*, 2017), phenolic acids (Lachman *et al.*, 2011; Benincasa *et al.*, 2015), flavonoids (Serpen *et al.*, 2008), alkylresorcinols (Andersson *et al.*, 2008), fibre (D´Antuono *et al.*, 1998; Kulathunga and Simsek,

2022) and trace minerals (Peleg *et al.,* 2008; Chatzav *et al*., 2010; Lachman *et al.*, 2011).

An emmer-base diet can reduce the diabetes incidence, preventing or delaying diabetes development (Thorup *et al.*, 2014; Gorelick *et al.*, 2017; Christopher *et al.*, 2018). Being non-gluten-free, emmer products may still be suggested to some patients with predisposition to celiac disease or other types of wheat intolerance (Vincentini *et al.,* 2007). All wheat species contain amylase-trypsin inhibitors (ATIs), but emmer showed a lower ATI activity than hexaploid wheat (Zevallos *et al.,* 2017), offering a potential to become a safe cereal for patients with gastroenterological pathologies.

With numerous papers on emmer published globally, efficient synthesis of this abundant information is essential for scientists to gain a comprehensive understanding of the current challenges, research trends and forthcoming prospects. Bibliometric analysis employs statistical methods and visualising approaches to dissect vast arrays of published data (Okubo, 1997; Van Raan *et al*., 2010). Bibliometric analysis enables researchers to timely identify the most relevant topics, patterns, trends and key findings. Major steps of bibliometric analysis include 1) Data retrieval from databases; 2) Data screening, cleaning, merging and refining; and 3) Processing of data with different bibliometric tools (Passas, 2024). Unlike literature reviews, which summarise and synthesise specific and relatively small datasets and meta-analyses, which summarise evidence from homogeneous studies to uncover new relationships, bibliometric analysis summarizes large amounts of data to pinpoint trends and patterns by operating broad and large (not too specific) datasets, often from heterogeneous studies. In our case, we would say that a traditional literature review analyzes findings on emmer, while a bibliometric analysis review explores emmer research. To date, there are quite a many bibliometric publications devoted to wheat research in general (Giraldo *et al.*, 2019; Pérez-Pérez *et al*., 2024), bread wheat investigations for a certain period of time (Yuan and Sun, 2022), Turkish studies on pasta wheat (Tekin and Akar, 2024), Indian studies on wheat (Siwach, 2020), ploidy-based analysis (Chandra *et al*., 2024), research into wheat allergy (Zhan *et al*., 2024), etc., as well as a comprehensive traditional review on *T. dicoccum* (Biradar *et al*., 2022); however, to our knowledge, emmer research has not been addressed from a scientometric point of view.

Thus, we applied bibliometric tools to elucidate the knowledge structure within emmer research. Our objectives were to trace time profiles of scientific output in emmer research, to pinpoint core research content, prevailing directions and major patterns, to evaluate connection maps and to identify leaders in this field.

MATERIAL AND METHODS

Data Retrieval and Processing

We used specific keywords to retrieve literature from the Scopus database (data cut-off date was 08/18/2025). The datasets were extracted at the Library of the Yuriev Plant Production Institute of the National Academy of Agrarian Sciences of Ukraine. The search terms were as follows: "emmer" OR "emmer wheat" OR "wild emmer" OR "*Triticum dicoccum*" OR "*Triticum turgidum* subsp. *dicoccum*" OR "*Triticum turgidum* var. *dicoccum*" OR "*Triticum dicoccon*" OR "*Triticum turgidum* subsp. *dicoccon*" OR "*Triticum turgidum* var. *dicoccon*" OR "*Triticum dicoccoides*" OR "*Triticum turgidum* subsp. *dicococcoides*" OR "*Triticum turgidum* var. *dicoccoides*". In analysis, we included publications in English and in national languages (German, Chinese, Japanese, Ukrainian, etc.) provided they had an English abstract.

Recognizing that the earliest emmer-related literature in the reviewed database dates back to 1905, we selected a total corpus of 3,812 publications covering the period from 1905 to 2025. We used the CSV export option, with all data elements included. To make our analyses more specific, we eliminated duplicates and wrong positive retrievals, which finally left 2,383 documents for analyses. The algorithm of this study is depicted in Figure 1.

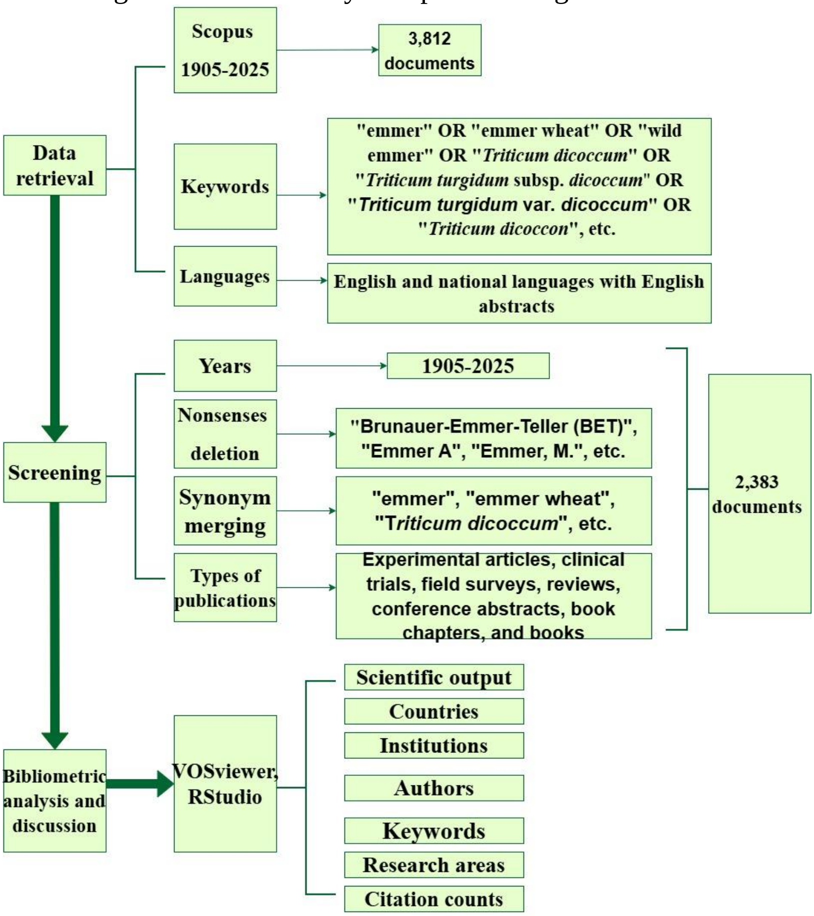

Figure 1. The study flowchart

The Annual Percentage Growth Rate (APGR) was calculated using the following formula: ((Ending Value - Beginning Value) / Beginning Value) × 100.

Data Visualization and Analysis

Various metrics such as the number of publications by countries and years, journal contributions, citations, etc., were sourced from the Scopus database. To gain information regarding the top most publishing countries, institutions and journals, most cited documents and most recurrent keywords as well as to visualize the results of metric frequency analysis and interaction analysis based on the Scopus dataset, we employed VOSviewer (version 1.6.20) and RStudio/Biblioshiny (version 2025.05.0-496). To merge name entries such as Nevo Eviatar and Nevo E., we reduced first names of authors to initials and used thesaurus files. We used thesaurus files to merge synonyms, like emmer, emmer wheat, *Triticum dicoccum*, spelling variants, like dietary fibre and dietary fiber, full terms and abbreviations, like single nucleotide polymorphism and snp, and singular and plural forms, like antioxidant and antioxidants. First, plots built in Biblioshiny were downloaded as PNG files; then we constructed their modifiable counterparts as vector images in RStudio, using codes written by Gemini or Claude and extracting plots as PDF files. Connection maps were created VOSviewer and extracted as PNG files. Tables include data calculated in Biblioshiny and extracted as XLSX files. The flowchart was constructed in the free online diagram software diagrams.net (formerly draw.io; JGraph Ltd., 2026).

RESULTS AND DISCUSSION

Time Profiles – Publications and Citations

The temporal evolution of the scientific output of emmer reserach is illustrated in Figure 2.

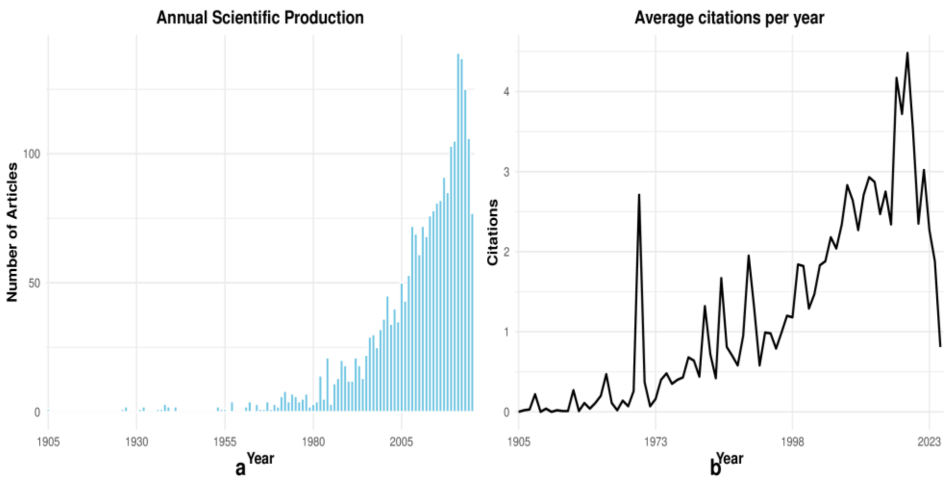

Figure 2. Temporal trends of emmer-related publications. A – Number of publications per year; B – Mean number of citations per year

The number of publications started steadily grow in the early 1980s (Figure 2a), which is understandable because the 1980s saw a renaissance of hulled wheat species (D'Antuono, 1995; Padulosi *et al*., 1996). The publication peak was reached in 2021. The APGR calculated for the period from 1982 (14 documents) to 2021 (139 documents) was 893%. After 2021, there were somewhat fewer publications in the following years. Does it mean that emmer has arrived at the end of its potential and is starting to seem less promising to researchers? We still think it is too early to make such a conclusion. The 2025 data are too immature and this decline may be another fluctuation, like those seen in 1998-1999 or in 2011-2013.

It should be noted that although there were a few publications on emmer during the period of 1905-1954, they had few citations or were not cited at all (Figure 2b). We see a sharp surge in the average number of citations per year in 1970 (2.7); then this parameter continued to increase, despite rather drastic fluctuations, until 2019 (4.5), indicating a growth both in the interest in emmer and in the publication quality. The APGR for the period from 1970 (the average number of citations per year was 2.7) to 2019 (4.5) was 67%. We believe that such a decline after 2019 does not mean that researchers lost interest in this subject as we can hardly suspect that the publication quality became worse; it is rather a short post-publishing period does not allow seeing the complete picture of citing the literature. Temporal changes in emmer-related publishing activities of top countries, institutions, authors, etc. are summarized in the corresponding sections below.

Sources

Table 1. Ten most relevant journals in emmer research

Publishing activity		Local impact	
Most publishing journals	Number of articles	Most citable journals	H-index*
Theoretical and Applied Genetics	157	Theoretical and Applied Genetics	54
Euphytica	93	Vegetation History and Archaeobotany	33
Vegetation History and Archaeobotany	90	Euphytica	32
Genetic Resources and Crop Evolution	75	Genetic Resources and Crop Evolution	24
Journal of Cereal Science	48	Journal of Cereal Science	24
Frontiers in Plant Science	47	Crop Science	23
Cereal Research Communications	43	Journal of Archaeological Science	20
Japanese Journal of Genetics	36	PLoS ONE	20
Journal of Archaeological Science	35	Plant Breeding	19
PloS ONE	34	Frontiers in Plant Science	18

**Note. The local H-index is calculated based on the analysed emmer research corpus (1905–2025).*

Given that articles (experimental articles + review articles + some conference proceedings) constitute a majority in the literature corpus under investigation, we further concentrated our analysis on top journals in this field. Table 1 shows that Theoretical and Applied Genetics is the most popular journal among authors in the field of emmer research. It is followed by Euphytica and Vegetation History and Archaeobotany. Local impact reflects how journals contribute to the academic advancements in their immediate surroundings versus in the global scholar community. Table 1 displays the local impact of the top 10 journals based on their H-index calculated specifically for the studied dataset. It is evident that articles published in Theoretical and Applied Genetics, Vegetation History and Archaeobotany and Euphytica are the most cited ones at present, so these journals are the leaders not only by quantity of emmer-related publications but also by citation count in this field.

The temporal progression of the journals' activities in this field is illustrated in Figure 3. Theoretical and Applied Genetics took the lead in 1988 and Vegetation History and Archaeobotany in 2007. At the dawn of emmer research, The Japanese Journal of Genetics was the leader for many years, but after 1995 its number of publications ceased increasing. The relatively recent dash of Vegetation History and Archaeobotany means that the significance of emmer in wheat evolution and the role of emmer in ancient cultures have gained rising interest in the academic community.

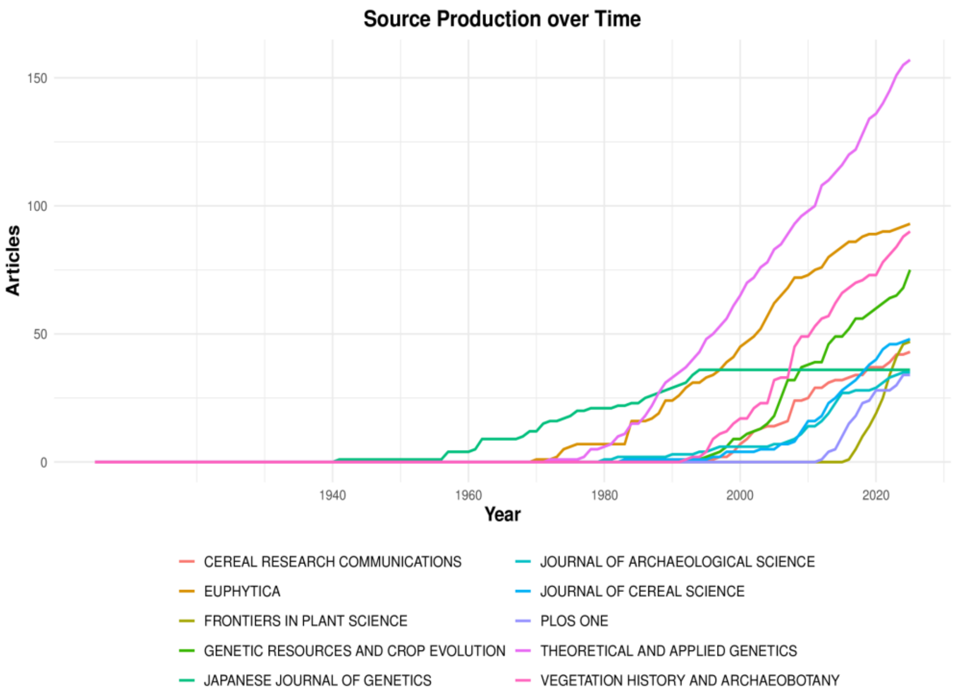

Figure 3. Temporal progression of the publishing activity of ten most relevant journals in emmer research

Top countries

We also analysed the scientific output of emmer-studying countries. Table 2 indicates that China, USA, Israel, Italy, Turkey, Germany, United Kingdom, India and Japan are the leaders in the emmer-related publishing activities. While China is the most prolific contributor, Israel remained the most cited one. In general, the lists of the most productive and the most cited countries are very similar.

Table 2. Ten most relevant countries in emmer research

Greatest contributors		Most citable countries	
Country	Number of documents	Country	Total Citation Count
China	1,966	Israel	4,588
Italy	1,210	China	3,342
USA	938	USA	3,318
Israel	897	Italy	3,128
India	604	Germany	2,482
Germany	551	Turkey	2,266
Turkey	402	United Kingdom	1,509
UK	402	France	1,109
Japan	307	Japan	771
Czech Republic	263	Czech Republic	588

For many years, Israel ranked first in the number of publications, with the USA and Italy alternately ranking second and third (Figure 4). From the beginning of this millennium, China showed a rapid rise, surpassing Italy, the USA and Israel by 2020.

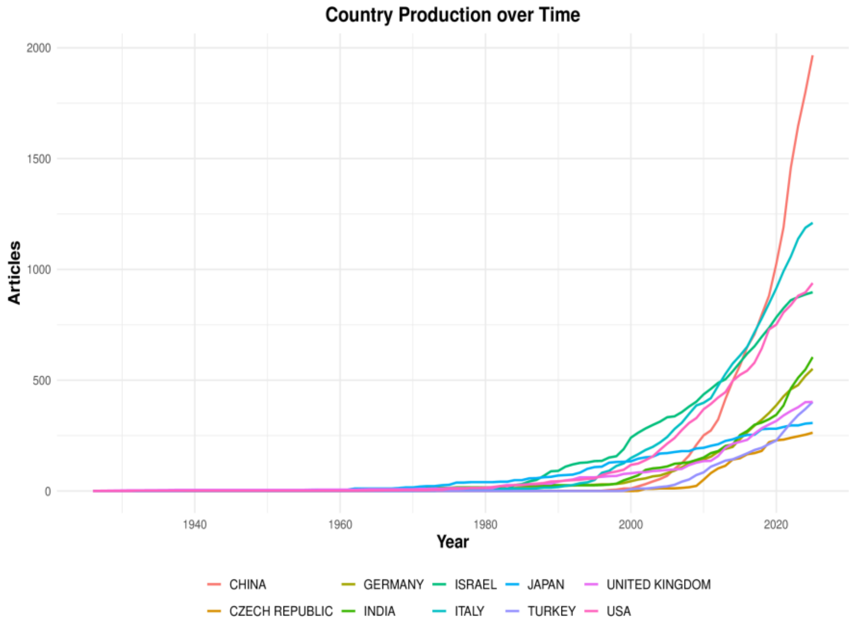

Figure 4. Publication productivity of the most relevant countries in emmer research over time

It is anticipated that Israel, Turkey, and Italy are among the most relevant countries in emmer research. The former two countries harbor rich populations of wild emmer. This abundance of genetic resources has historically driven intensive research in these regions (Nevo and Beiles, 1989; Özkan *et al*., 2011). Meanwhile, Italy's significant contribution is driven by its long-standing focus on wheat species suitable for high-quality pasta production. USA, Japan, Germany, France and other European countries are science-oriented countries in general; in addition, many of these countries have turned their attention to ancient wheat species since the 1980s. China's rapid advancement in this field can be explained by great interest in the whole genus *Triticum* (Xiao *et al.*, 2022; Zhuang *et al*., 2024).

We have also summarized intra- and inter-country cooperation in the emmer-related publishing activities of the top countries. According to the multi-country to single-country publication ratio, the countries were ranked as follows: Israel (61.4%) > United Kingdom (60.7%) > China (39.3%) > USA (38.4%) > Germany (36.7%) > Italy (28.7%) > Czech Republic and India (27.3%) > Japan (26.7%) > Turkey (18.2%), showing quite high percentages of inter-country collaboration for the major contributors.

The connection map (Figure 5) illustrates distribution and collaboration among countries engaged in emmer research.

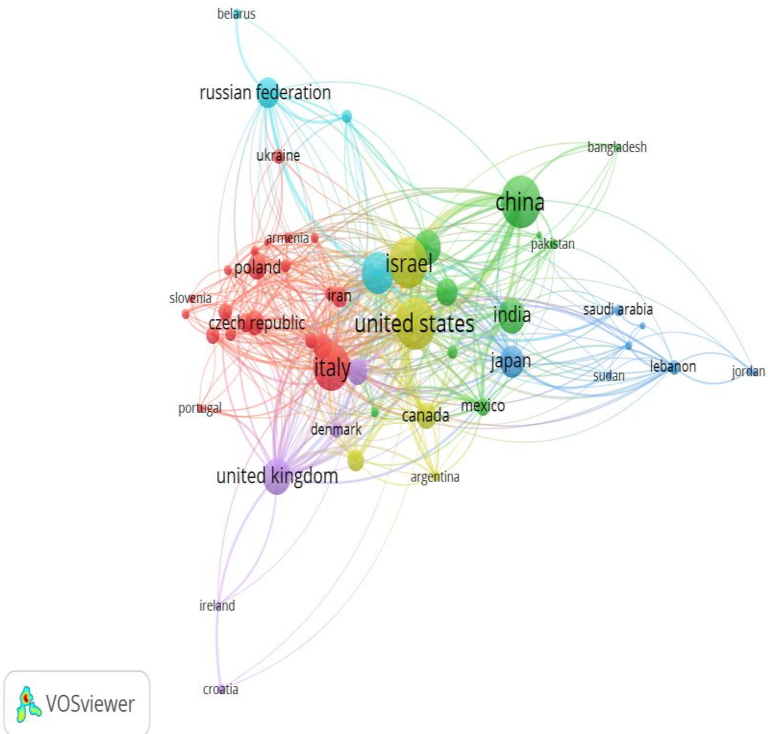

Figure 5. Co-authorship map for countries (frequency ≥ 5; total link strength)

Analysis of the Scopus dataset in VOSviewer grouped 54 countries in 6 clusters. The yellow cluster contains two of the greatest contributors, Israel and the USA, with China being in the green cluster. Other publishing-active countries, such as Germany, United Kingdom, Turkey, Japan, Italy, fall into different clusters: Italy is in the red cluster, United Kingdom – in the lilac cluster, Japan – in the dark-blue cluster, Turkey – in the green cluster, Germany – in the light-blue one, etc. The most prolific contributors, China and Israel, have established collaborative ties with 24 and 29 countries, respectively. Lines between countries show link strength. For example, the total link strength between the USA and Israel is 80 and it is the strongest connection. For comparison, the total link strength between the USA and Ukraine is 2.

Institutions

Furhter, instutions were evaluated for scientific output. Our analysis identified the ten most prolific affiliations, which are ranked in descending order as follows: University of Haifa (499 articles) > Sichuan Agricultural University (463) > Northwest A&F University (266) > North Dakota State University (174) > China Agricultural University (166) > Università degli Studi di Bari Aldo Moro (142) > University of California (140) > Hebrew University of Jerusalem (137) > Institute of Cytology and Genetics (100) > (Tel Aviv University (99).

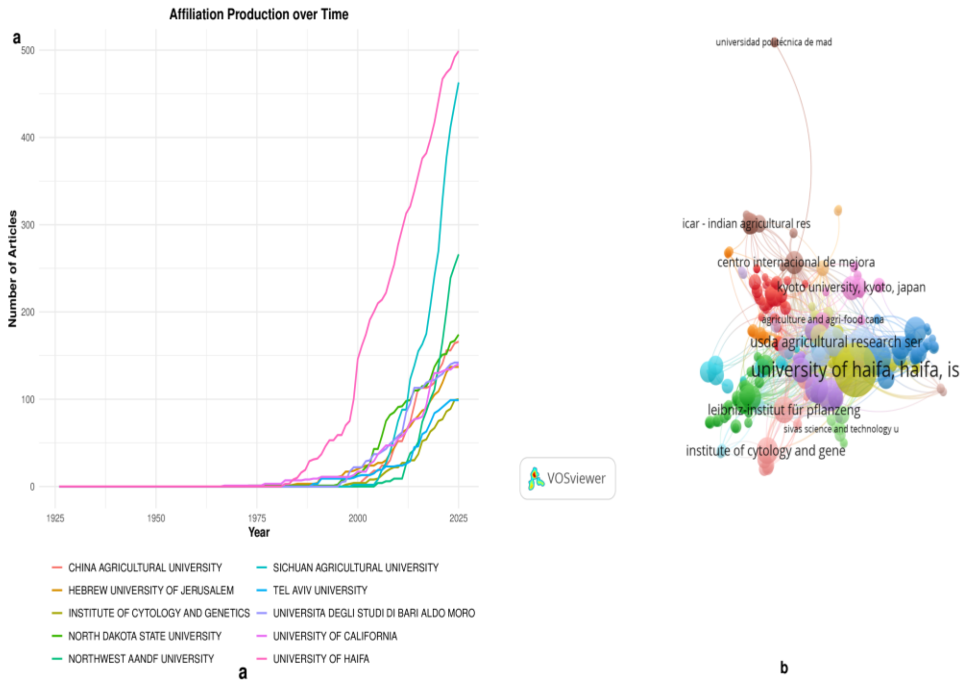

Figure 6. Most relevant institutions in emmer research. a – Institutions' production over time; b – Collaboration network (frequency ≥ 5; total link strength)

Figure 6a demonstrates that the University of Haifa has been the leader in the emmer related publishing activities for the entire period of analysis. Sichuan Agricultural University moved ahead of the other leading organizations in 2013, nearly equaling the output of the University of Haifa. Of 1,703 affiliations, VOSviewer identified 234 organizations that met the clustering threshold and grouped them in 17 clusters (Figure 6b). The yellow cluster with University of Haifa and University of California (Davis) stands out. The second ranking Sichuan Agricultural University is in the dark-blue cluster. University of Haifa has established 78 collaboration links with the total strength of 369 and published 199 documents. For comparison, Peking University (dark-blue cluster), for example, has established 8 collaboration links with the total strength of 13 and published 7 documents.

Leading Authors and Research Topics

A total of 5,517 authors contributed to emmer-related literature. The scientific outputs of the leading researchers, i.e. their publication counts and H-indices, are summarised in Table 3. Nevo Eviatar and Fahima Tzion, who rank first and second, are undeniably the most publishing authors in emmer research, outpacing the other top-ranking authors. Nevo E. and Fahima T. have the highest values of H-index, meaning that they are not only the most prolific authors but also the most cited ones.

Table 3. Most relevant authors in emmer research

Authors	Number of articles	Author	H-index
Nevo, Eviatar	113	Fahima, Tzion	45
Fahima, Tzion	80	Nevo, Eviatar	44
Beiles, Avigdor	36	Korol, Abraham B.	26
Korol, Abraham B.	36	Beiles, Avigdor	23
Krugman, Tamar	34	Peleg, Zvi	22
Peleg, Zvi	31	Röder, Marion S.	21
Zheng, Youliang	31	Saranga, Yehoshua	21
Saranga, Yehoshua	30	Blanco, Antonio	20
Faris, Justin D.	28	Krugman, Tamar	20
Xu, Steven S.	27	Faris, Justin D.	19

From Figure 7a, it is clear that the most prolific author, Nevo E., started publishing emmer-related articles as early as in 1984 and continues his publishing activity till now. He works at the Institute of Evolution, University of Haifa. It appears that his work has made the University of Haifa the main contributor to emmer-related literature and Israel the most influential country in this field. The other top authors have much shorter periods of emmer-related publishing activities, except for Beiles A. (Institute of Evolution, University of Haifa; 1984-

2019) and Krugman T. (Institute of Evolution, University of Haifa; 1986-nowadays), who have been publishing emmer-related articles for a long time. As to citation counts for the entire analyzed period (Figure 7a), Nevo E. and Fahima T. (also working at the Institute of Evolution, University of Haifa) had the highest total count per year: Nevo E. reached over 30 citations per year in 2010-2011 and Fahima T. had over 30 citations per year in 2003 and 2009. VOSviewer analysis of the Scopus dataset found that 425 authors met the clustering threshold and grouped them in 17 clusters in the connection map (Figure 7b). Nevo E. (pink cluster) and Fahima T. (yellow cluster) rank the first in this analysis: they have established 69 and 62 collaboration ties with the total link strength of 316 and 370, respectively. Nevo E. has published 113 documents with the total citation count of 6,227 and Fahima T. has published 80 documents with the total citation count of 5,853.

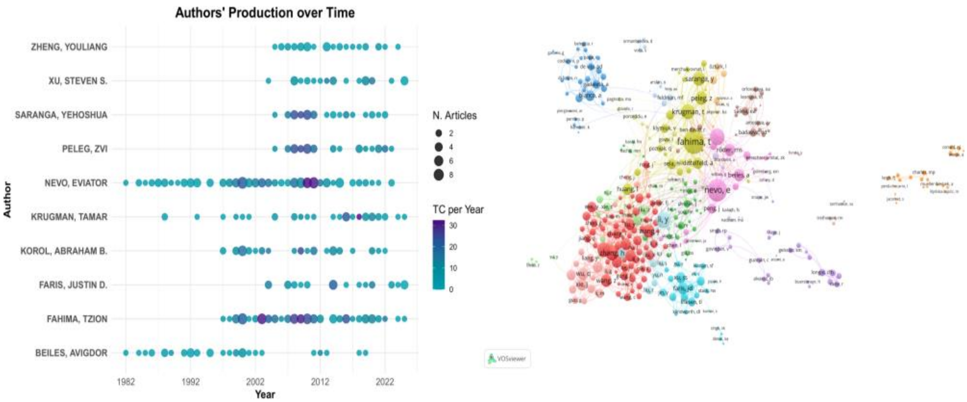

Figure 7. Most relevant authors in emmer research. a – Production over time (the size of circles corresponds number of publications and the tinting strength means citation count); b – Collaboration network (frequency ≥ 5; total link strength).

We selected the 30 most cited articles (over 200 citations), which are listed Table 4. Having reviewed these articles, we distinguished major directions in emmer research: 1) Wheat origin, evolution and domestication. It seems that these issues make up the greatest mainstream in emmer research. Anvi *et al.* (2017) reported about a 10.1-gigabase assembly of the 14 chromosomes of wild emmer and findings on gene content, genome architecture and genetic diversity. The authors revealed "genomic regions bearing the signature of selection under domestication." Maccaferri *et al.* (2019) also described regions exhibiting conspicuous signatures of domestication-associated genetic divergence. Haudry *et al.* (2007) estimated "the intensity of the bottlenecks associated with domestication and subsequent selection." According to their estimate, a domesticated emmer population size was about one third of a wild emmer population size. Studying such traits as brittle rachis, heading date, plant height, grain size, yield and yield components, Peng J. *et al.* (2003) mapped domestication-related quantitative trait loci in *T. dicoccoides*. Research often addresses the place of emmer in the general picture of wheat evolution and domestication (Evans and Dunstone, 1970; Matsuoka, 2011; Peng *et al.*, 2011). 2) Grain quality. Specifically, mineral micronutrient levels are a hotspot. Emmer grain was shown to contain significantly more selenium than common or durum wheat (Zhao *et al*., 2009). Cakmak *et al.* (2004) and Peleg *et al*. (2009) demonstrated that wild emmer was a valuable genetic resource for increasing zinc and iron contents in modern cultivars. Distelfeld *et al.* (2007) obtained similar results. In addition, they demonstrated that emmer was also richer in manganese and protein than modern durum wheat. In a durum wheat line carrying *T. dicoccoides* chromosomes, Joppa *et al.* (1997) identified markers that could be used in marker-assisted breeding for high grain protein content in durum wheat. High grain protein content is a frequent target of wheat breeding programmes; hence the grain protein content locus has been intensively investigated, including its pleiotropic effects (Uauy *et al.,* 2006). Dietary fibre is a valued ingredient of grain, hence the study where a set of wheat accessions had been screened for contents of dietary fibre and components thereof was highly cited (Gebruers *et al*., 2008). This set was also screened for levels of tocols, sterols, phenolic acids, folates and alkylresorcinols (Ward *et al.*, 2008). Bioactivity of amylase-trypsin inhibitors (ATIs) is another indicator of grain quality that has been a frequent subject of studies. Emmer products were shown to have lower ATI bioactivity than modern hexaploid wheat (Zevallos *et al.*, 2017). Arzani and Ashraf (2017) summarized benefits of ancient wheat species, including emmer, as potential sources of healthy foods. However, Shewry and Hey (2015) rebutted the opinion that ancient wheats were healthier than modern wheats. 3) Biology of pathogens and resistance to diseases. Biology of wheat pathogens (especially fungi) has been a research mainstream for a long time (Bolton *et al*., 2008). Emmer is noticeable for resistance to fungal pathogens. Wild emmer carries several genes for resistance to yellow rust: Yr15, Yr35 and Yr36 (Uauy *et al*., 2005; Chen *et al.,* 2014; Klymiuk *et al.,* 2018). 4) Tolerance to abiotic stresses. It is another advantage of this ancient wheat. Nevo and Chen (2010) identified drought- and salt-tolerant genes and quantitative trait loci (QTLs) in *T. dicoccoides* and highlighted a great potential for wheat improvement. Turkish scientists also studied response of wild emmer to drought stress and discovered 13 microRNAs that were differentially regulated in response to drought (Kantar *et al*., 2011). 5) Molecular breeding approaches. It is often difficult to separate this research direction from others, as molecular genetic methods are widely used to improve grain quality or to enhance resistance to diseases, etc. However, some influential publications were devoted specifically to approaches and tools. For example, Maccaferri *et al.* (2015) assembled a high-density tetraploid wheat consensus map that could be used for wheat breeding purposes. 6) Nucleic acid sequence polymorphism. This direction is also difficult to separate from others because the sequence polymorphism studies often deal with grain quality traits, or agronomic characteristics, or resistance to unfavourable conditions, etc. Nevertheless, there are influential articles devoted nucleic acid sequence polymorphisms per se (Appels and Dvořák, 1982). We should, nonetheless, point out that such findings often carry evolutionary or breeding implications. 7) Early cultivation. Studies on the roles of emmer and other wheat species in early cultures stand apart in the corpus of biological and agricultural research. Nonetheless, we cannot ignore this theme as it is among top ones and publications on pre-domestication cultivation in the pre-Neolithic and Neolithic era are on the list of the most cited articles (Boardman and Jones, 1990; Willcox *et al.*, 2008; Riehl *et al.*, 2013). It should be noted that the paleobotany and archaeobotany theme is closely intertwined with the domestication theme (Willcox, 2005).

Table 4. Most cited emmer-related articles in the Scopus dataset

No	Publication	Total citation count	Major directions
1	Avni *et al.* (2017)	627	Wheat origin, evolution and domestication
2	Maccaferri *et al.* (2019)	551	Wheat origin, evolution and domestication
3	Zhao *et al.* (2009)	427	Grain quality
4	Chen *et al.* (2014).	393	Biology of pathogens and resistance to diseases
5	Bolton *et al.* (2008)	373	Biology of pathogens and resistance to diseases
6	Nevo and Chen (2010).	364	Tolerance to abiotic stresses
7	Kantar *et al.* (2011)	341	Tolerance to abiotic stresses
8	Cakmak *et al.* (2004)	320	Grain quality
9	Haudry *et al.* (2007)	312	Wheat origin, evolution and domestication
10	Matsuoka (2011)	296	Wheat origin, evolution and domestication
11	Zevallos *et al.* (2017)	281	Grain quality
12	Peng *et al.* (2003)	280	Wheat origin, evolution and domestication
13	Klymiuk *et al.* (2018).	259	Biology of pathogens and resistance to diseases
14	Arzani and Ashraf (2017)	259	Grain quality
15	Distelfeld *et al.* (2007)	258	Grain quality
16	Peng *et al.* (2011)	249	Wheat origin, evolution and domestication
17	Joppa *et al.* (1997)	247	Grain quality
18	Peleg *et al.* (2009)	245	Grain quality
19	Willcox *et al.* (2008)	244	Early cultivation
20	Uauy *et al.* (2006)	239	Grain quality
21	Evans and Dunstone (1970)	238	Wheat origin, evolution and domestication
22	Gebruers *et al.* (2008)	236	Grain quality
23	Maccaferri *et al.* (2015)	234	Molecular breeding approaches.
24	Boardman and Jones (1990)	228	Early cultivation
25	Ward *et al.* (2008)	224	Grain quality
26	Uauy *et al.* (2005)	219	Biology of pathogens and resistance to diseases
27	Shewry and Hey (2015)	215	Grain quality
28	Riehl *et al.* (2013)	215	Early cultivation
29	Willcox (2005).	213	Early cultivation; wheat evolution and domestication
30	Appels and Dvořák (1982)	212	Nucleic acid sequence polymorphism

Here we can also trace some regional peculiarities in emmer research. For example, Turkish researchers are more focused on drought tolerance (Budak *et al.*, 2013), which can be explained by the country's climatic conditions, while Israeli triticologists have made use of their (and Turkish) populations of wild emmer (Nevo and Beiles, 1989; Peng *et al*., 2003; Cakmak *et al.*, 2004).

Research Hotspots and Evolution Trends

Since there is a notion that author keywords are highly subjective and lack statistical uniformity (Qin *et al.*, 2021), at first we used Keywords Plus in RStudio and Index Keywords in VOSviewer to achieve greater relevance in this study (data are not presented). However, we found that Keywords Plus- or Index Keywords-based clusters poorly reflect the actual state in emmer-related literature and in some cases do not corroborate with each other. Zhang *et al.* (2016) pointed out that Authors' Keywords and Keywords Plus were equally effective in terms of bibliometric analysis to investigate the knowledge structure, but Authors' Keywords better represented contents of publications. Hence, we decided on using authors' keywords.

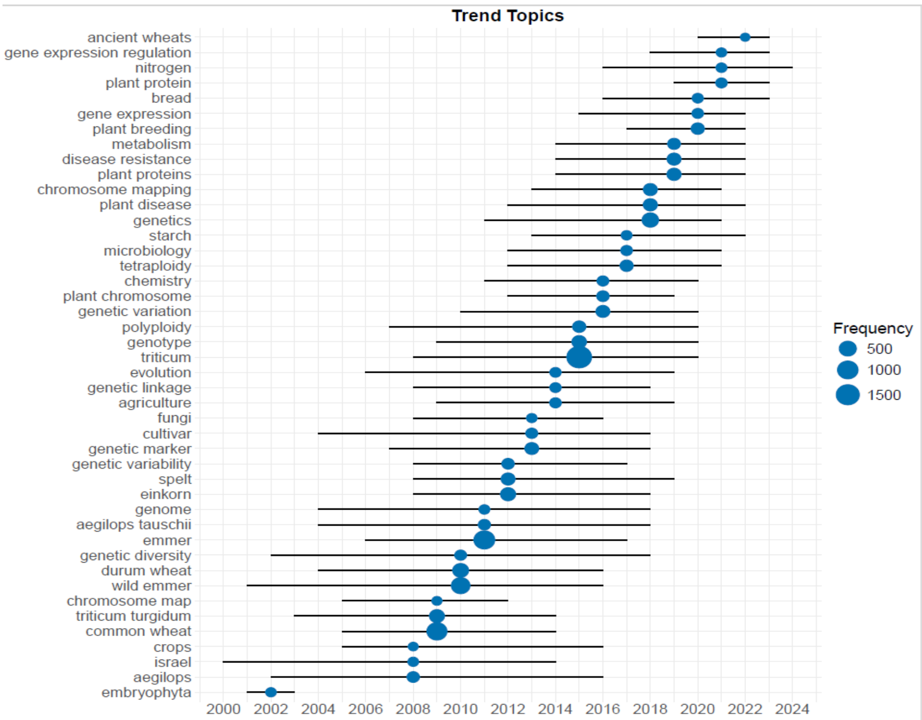

Figure 8. Keywords with the strongest occurrence bursts (word minimum frequency – 50; number of words per year – 3)

Here, ten the most frequent keywords are listed in the descending order: *Triticum* (1,483 occurrences) > common wheat (807) > emmer (612) > genetics (423) > wild emmer (350) > durum wheat (266) > *Triticum turgidum* (257) > genotype (247) > plant disease (216) > einkorn (212). This confirms that resistance to diseases, improvement of widely cultivated wheat species, wheat genetics and related ancient wheat species are the most frequent subjects in emmer research.

Trend Topics plots provide visualization of research focal points over time. They help assess which themes arouse persistent research interests, what themes are likely to become future research directions and that themes can be considered as exhausted or currently irrelevant. Circles denote medians of term frequencies. The biggest circles for the keywords '*Triticum'*, 'common wheat', 'wild emmer' and 'emmer' reflect the significant attention devoted to these topics (Figure 8). The themes, such as 'genetic diversity', 'wild emmer', '*Aegilops'*, appear to be subjects of rather persistent research interests, as they emerged with high frequencies for 16, 15 and 14 years with the medians in 2010, 2010, 2016 and 2008, respectively. The themes 'ancient wheats', 'gene expression regulation' and some others, which have appeared recently, may become future research directions. The term 'embryophyta' disappeared from emmer-related literature in 2003, meaning this topic is not linked with emmer research hotspots any longer.

Keyword clustering elucidates relationships between keywords, allowing one to pinpoint research hotspots. The visualization of the Scopus dataset in VOSviewer identified 5 rather heterogeneous clusters (of 9,817 keywords, 447 met the clustering threshold; Figure 9a). The largest red cluster in the connection map focuses on domestication, organic farming, breeding, grain quality, related cereal species, yield, germination and other issues. The second largest, green cluster, is concentrated around genetics and disease resistance: plant chromosomes and genes, phenotype, quantitative trait loci, genetic maps and linkage, biomarkers, immunology and fungal pathogens. The blue cluster is significantly smaller, focusing on evolution, genetic variability, ploidy levels, plant genome and wild related species. The yellow cluster includes more biochemical and physiological issues: metabolism, gene expression regulation, transcriptome, plant proteins, resistance to abiotic stresses and many minor issues. The smallest, lilac cluster includes classification, phylogeny and molecular evolution. It is noteworthy that such topic as plant genetics or evolution are so broad and comprise so many multifarious aspects that it is impossible to place them in one cluster. Figure 9b elucidates the categorization of themes in emmer research. In such maps, each cluster named after the most common words is represented as a bubble. The bubble size is determined by word frequency in the cluster. The X-axis measures the cluster's centrality (relevance) in the network, i.e., the degree of interaction with other clusters in the map, evaluating the importance of research themes (Bastazini, 2025) The Y-axis measures development (density), i.e. the strength of work within the cluster and the theme growth. Basic themes (lower right quadrant) are usually characterized by high centrality and low density. They are often essential for transdisciplinary investigations and may serve as foundational topics for multiple themes, but these themes have few connections. This plot contains one big blue bubble right between this quadrant and the Motor Themes. We would describe it as the "emmer and related species bubble", as it contains keywords 'emmer', 'wild emmer', 'durum wheat', 'common wheat', '*Triticum turgidum*' and '*Aegilops*', but it also includes themes 'genetic variability' and 'genotype'. Motor Themes (upper right quadrant) are characterized by high centrality and density, indicating that they are well-developed and crucial for structuring the research field. The Motor Themes in our study encompass keywords 'genetics', 'plant chromosomes', 'plant genes', 'alleles', 'plant proteins', 'metabolism' and 'phylogeny' (green bubble in the upper right corner). In addition, half of the yellow bubble is in the upper right quadrant, too. This bubble covers such topics as 'chromosome mapping', 'plant diseases', 'disease resistance', 'fungi', 'genetic markers' and 'microbiology'. The other half of the orange bubble belongs to the Niche Themes. Niche Themes (upper left quadrant) are highly specialized and well-developed in terms of internal research but also have limited interactions with other research themes. In our analysis, the Niche Theme quadrant contains no bubbles of themes that could be classified as purely niche. Peripheral themes or Emerging or Declining Themes (lower left quadrant) are themes with low centrality and low density, suggesting that they are underdeveloped and marginal, i.e. either emerging or declining in the literature. One "archaeobotanical" bubble (the small lilac bubble) represents such themes in the lower left corner of the plot in Figure 9b. The Emerging or Declining Themes in this analysis also contain the red bubble, which is somewhat similar to the blue bubble, as it also includes keywords designating related cereal species; however, the list of species is different: the red bubble has keywords 'einkorn', 'spelt', 'barley' and 'rye'. The red bubble also contains the general terms 'cultivation' and 'agriculture'.

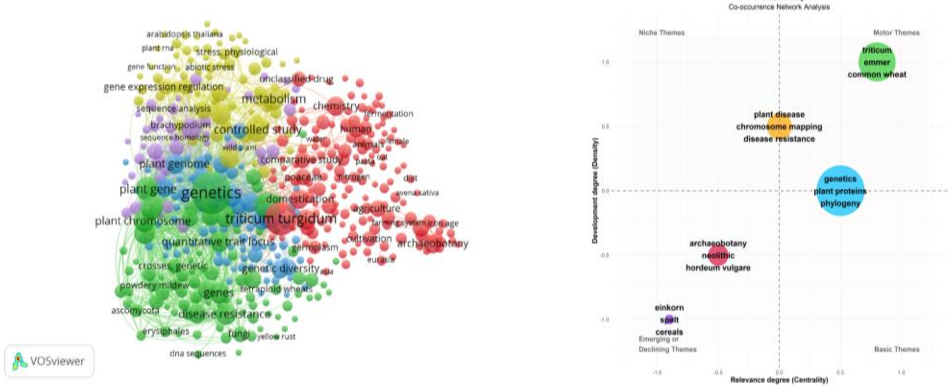

Figure 9. Keywords co-occurrence network in emmer research. a – VOSviewer map (frequency ≥10); b – thematic keywords (minimal cluster frequency per 1,000 documents – 5)

CONCLUSIONS

The bibliometric analysis indicates a transformative shift in emmer research from sporadic historical observations to a dynamic, multifaceted field of modern cereal science. While traditional studies focused on wheat origin and domestication, the current landscape is increasingly dominated by molecular breeding and the exploration of nucleic acid sequence polymorphism. The transition of leadership in publication output to China, alongside the sustained high contributions of Israeli and American institutions to the total scientific output, reflects a global strategic interest in diversifying wheat genetic resources.

The core research mainstreams—ranging from grain quality to biotic and abiotic stress resistance—underscore the growing recognition of emmer as a critical reservoir for crop improvement. Future scientific endeavours are expected to prioritize the physiological and genetic mechanisms of stress tolerance. Specifically, the introgression of beneficial traits from wild and cultivated emmer accessions into advanced common and durum cultivars remains a vital frontier for ensuring global food security in the face of climate change. These findings highlight emmer not only as a subject of evolutionary interest but as a valuable starting material for sustainable wheat breeding.

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DECLARATION OF AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, we used AI tools (Gemini and Claude) for technical assistance. Specifically, these tools were employed to generate R-codes for creating high-resolution vector visualizations in RStudio (as detailed in the Materials and Methods section), to improve our English, and to format the bibliographic references according to the journal's style. Following the use of these tools, we all reviewed and edited the manuscript, taking full responsibility for the final scientific content and the accuracy of the reference list.

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