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Bibliometric analysis of maize ear separation technologies for seed purposes based on the Scopus database

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Abstract: To perform a bibliometric analysis of scientific research on maize ear separation technologies for seed purposes and to identify publication dynamics, leading countries, and thematic trends in this field. Publications indexed in the Scopus database for the period 2020–2025 were retrieved using an advanced search query. A total of 291 documents were selected and analyzed using Microsoft Excel, VOSviewer, and MapChart. Document types, annual publication trends, country distribution, co-authorship networks, and the evolution of research keywords were examined. Scientific output increased substantially in recent years, and journal articles were the dominant document type. China and the United States were identified as the leading contributors. Keyword analysis revealed a clear transition from conventional agronomic and mechanical approaches toward near-infrared spectroscopy, artificial intelligence, and data-driven methodologies. Maize ear separation technologies are rapidly evolving toward intelligent, automated, and high-precision systems, which provides a solid foundation for future research and technological development.

Keyword: Maize; maize ear; seed separation; sorting technologies; artificial intelligence; machine learning; bibliometric analysis; VOSviewer

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1. Introduction

Maize is one of the most significant cereal crops worldwide, playing a critical role in ensuring food security, supporting livestock production, and meeting industrial demands. Currently, global maize production exceeds 1.1 billion tons annually, making it one of the cornerstone crops of modern agricultural systems. In seed production processes, the accurate selection and separation of maize ears are crucial for obtaining high-quality seed material [1,2]. Inefficient separation directly affects seed uniformity, germination rate, and overall crop productivity [3,4]. However, conventional sorting methods are typically labor-intensive, time-consuming, and characterized by limited accuracy [5]. These limitations often result in reduced seed quality, uneven germination, and decreased efficiency of technological processes.

In recent years, research efforts aimed at improving maize ear separation technologies have intensified significantly. In particular, the development of mechanical sorting systems, vibration-based separation mechanisms [6–8], optical and sensor-based technologies [9–11], as well as artificial intelligence and machine learning approaches, has gained considerable attention [12,13]. These technological advancements contribute to increasing sorting accuracy, minimizing human intervention, and enhancing overall process efficiency.

Despite these developments, existing studies remain fragmented across various sources, and a systematic evaluation of global research trends in this field is still insufficient. In this context, bibliometric analysis has emerged as an effective methodological approach for comprehensively assessing scientific activity, identifying leading countries and research groups, and revealing emerging research directions [14]. Therefore, the main objective of this study is to perform a bibliometric analysis of scientific publications related to maize ear separation technologies for seed purposes based on the Scopus database. The study focuses on analyzing publication dynamics, leading countries,

document types, co-authorship networks, and keyword evolution. The results obtained provide valuable insights into the current state of research and serve as a scientific basis for the development of advanced and efficient separation technologies.

2. Materials and Methods

In this study, a bibliometric analysis of scientific publications related to maize ear separation technologies and devices for seed purposes was conducted using the Scopus database as of 2025. Scopus is one of the most authoritative international scientific databases, providing comprehensive coverage of high-quality publications across various research fields.

The advanced search strategy was developed based on the following query:

As a result of this query, scientific data covering the period from 2020 to 2025 were retrieved from the Scopus database. The study encompassed several subject areas, including agricultural and biological sciences, engineering, environmental sciences, materials science, and food technology. A total of 291 publications were selected for analysis. Statistical analysis was performed using Microsoft Excel, which is a widely used and effective tool for data processing, visualization, and quantitative analysis. This software was employed to analyze document types, annual publication trends, and the distribution of research activity across countries.

In addition, VOSviewer and MapChart software tools were utilized to enhance the depth of the bibliometric analysis. VOSviewer enables the visualization of relationships between scientific publications, authors, and keywords, and is widely recognized as an effective tool for identifying research trends and thematic structures [14]. MapChart was used to illustrate the geographical distribution of scientific output. Figure 1 presents the step-by-step workflow of the adopted research methodology. The selection of this methodological approach is justified by the reliability of the Scopus database, its extensive coverage of high-impact scientific publications, and its global recognition as a leading academic platform.

Furthermore, English was selected as the primary language of analysis, as it is the dominant language of scientific communication and ensures broader accessibility, standardization, and comparability of research outputs within the global scientific community.

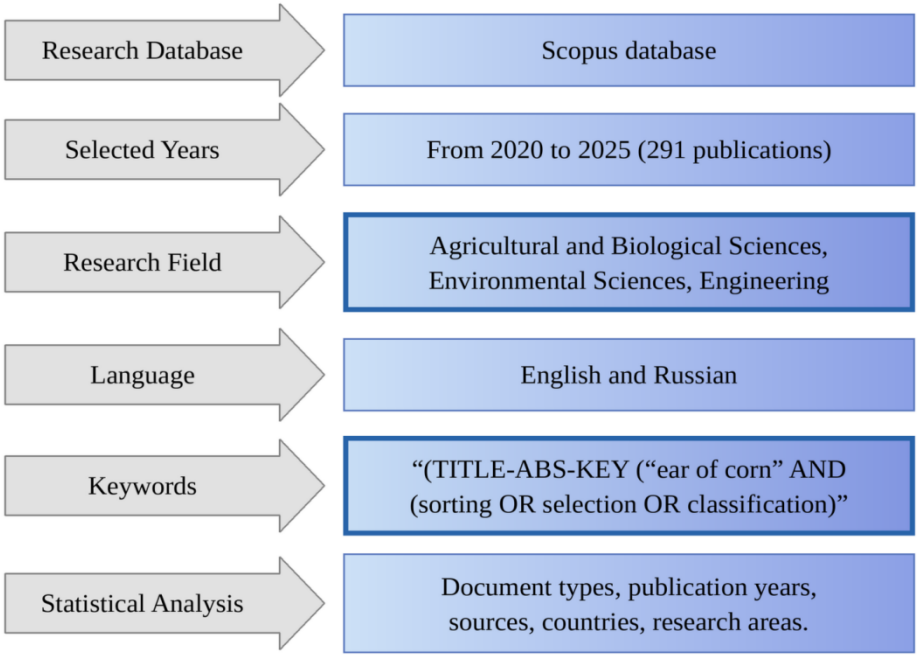


Figure 1. Research methodology framework adopted for the bibliometric analysis.

3. Results and Discussion

3.1. Annual publication trends

The temporal distribution of publications indexed in Scopus for the period 2020–2025 reveals a consistent upward trend, indicating growing scientific interest in maize ear separation technologies (Figure 2). The annual number of publications increased from 4 in 2020 to 50 in 2025, a 12.5-fold rise, which corresponds to a compound annual growth rate of approximately 65.7%. Two distinct stages can be identified in this dynamic.

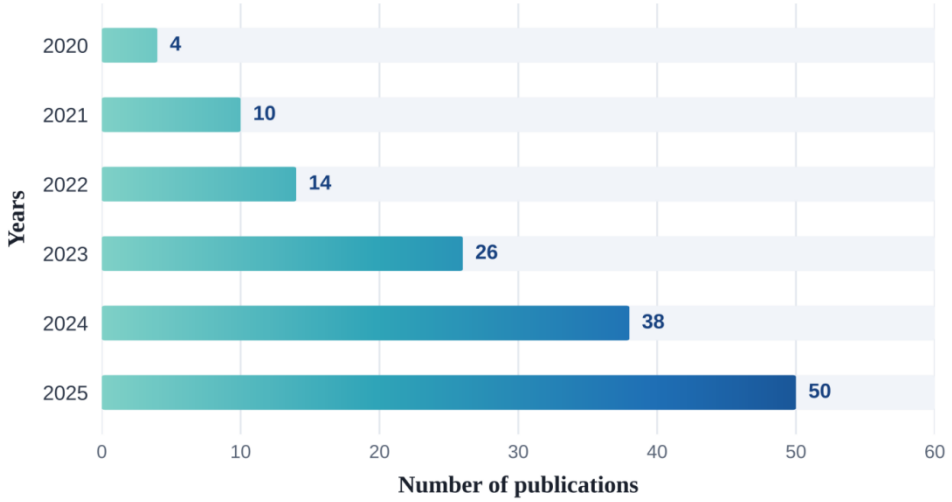


Figure 2. Annual distribution of scientific publications on maize ear separation technologies during the period 2020–2025.

The first stage (2020–2022) is characterized by moderate growth, with the annual output rising from 4 to 10 and then to 14 publications. During this period, a total of 28 papers were published, accounting for 19.7% of the analyzed sample. Research in this phase was primarily focused on the fundamental theoretical and design aspects of separation and processing systems [6,15].

The second stage (2023–2025) demonstrates a pronounced acceleration of scientific activity, with 26, 38, and 50 publications recorded in 2023, 2024, and 2025, respectively. These three years account for 114 publications, or 80.3% of the total output. This shift indicates a transition from exploratory studies toward the refinement of existing technologies and the expansion of applied research.

Several factors may explain this growth. First, the increasing demand for high-quality seed material [16] has intensified the need for more efficient separation and processing technologies. Second, the integration of advanced solutions in agricultural engineering, such as precision agriculture, sensor-based monitoring, and intelligent control systems, has improved the efficiency and optimization of separation processes [7,17]. Third, reducing grain losses and mechanical damage during processing [6,7] has become a critical research challenge, further stimulating scientific investigation in this field.

The observed trend is also consistent with global processes of agricultural mechanization and digitalization. The wider adoption of vibration-based systems, automated control, and data-driven optimization methods [18,19] has contributed to the expansion of research activity. The sharp increase after 2022 may additionally be associated with greater research funding, closer international collaboration, and the rising global priority of food security, which underscores the strategic importance of maize as a key agricultural crop.

In summary, the bibliometric analysis confirms that maize ear separation technologies constitute a rapidly developing research field. This trend substantiates the relevance of the present study and highlights the need for scientifically grounded design and operational parameters of seed-oriented separation and processing devices.

3.2. Types of scientific publications on maize ear separation technologies

The analysis of publication types indicates that the majority of scientific outputs are journal articles, accounting for 84% of the total publications (Figure 3). This dominance reflects that research in this field is primarily disseminated through high-quality, peer-reviewed journals, ensuring the reliability, experimental validation, and methodological rigor of the reported results. Such a scientific approach is particularly important for technologies aimed at improving seed quality and separation efficiency.

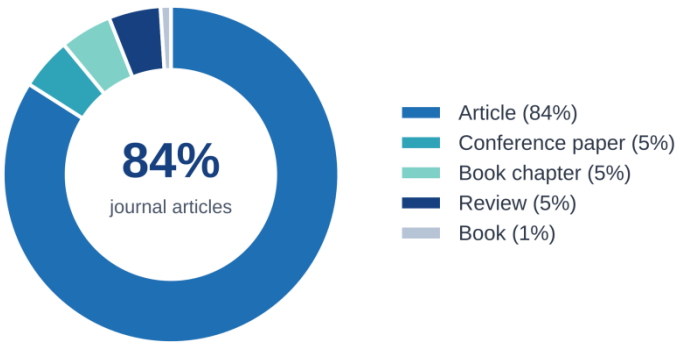


Figure 3. Distribution of scientific publications on maize ear separation technologies by document type.

Conference papers constitute approximately 5% of the publications and play a significant role in the rapid dissemination of emerging research findings and the discussion of novel technological developments. Review articles, also representing about 5%, contribute to the synthesis of existing knowledge and the identification of future research directions. Book chapters (5%) indicate that a portion of the research outcomes is also presented in edited volumes and monographs, while books (1%) suggest that comprehensive, large-scale fundamental studies in this field remain relatively limited. Overall, the predominance of journal articles highlights the dynamic development of this research area and indicates that most studies are focused on applied and experimental investigations. At the same time, the relatively low proportion of review articles underscores the need for more systematic and integrative studies to consolidate existing knowledge and guide future research.

3.3. Leading countries in research on maize ear separation for seed purposes

The analysis reveals that research activity in this field is concentrated in a limited number of countries (Figure 4). In particular, China (89 publications) and the United States (61 publications) occupy leading positions, contributing the largest share of the total scientific output. China's leadership can be attributed to its large-scale agricultural sector, high maize production volume, and substantial investments in the mechanization and digitalization of agriculture. The United States, on the other hand, demonstrates strong and consistent research performance supported by advanced agricultural engineering and highly efficient technological systems.

In addition, countries such as Brazil (12 publications), Iran (8 publications), and Canada (7 publications) also make notable contributions to this research area. These countries are characterized by significant maize production and a relatively high level of technological development. Furthermore, Indonesia (6 publications), Mexico (6 publications), Germany (5 publications), Argentina (4 publications), and India (4 publications) also participate actively, although at a comparatively lower level. Geographical analysis indicates that research activities are primarily concentrated in regions with well-developed agricultural sectors and high maize production capacity. In contrast, regions such as Central Asia and Africa exhibit relatively low research output, suggesting the presence of underexplored scientific gaps in this domain. Overall, these findings confirm a strong interconnection between agricultural development, technological advancement, and scientific productivity. They also highlight the need for expanding research efforts and fostering international collaboration to further advance maize ear separation technologies for seed purposes.

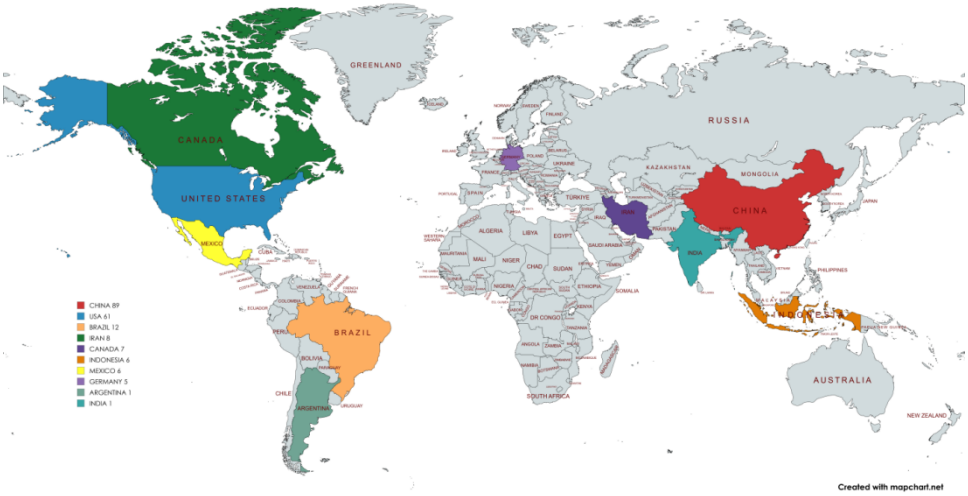


Figure 4. Geographical distribution of leading countries in research on maize ear separation technologies for seed purposes.

3.4. Co-authorship and keyword network visualization in research on maize ear separation

The overlay visualization of keyword co-occurrence (Figure 5) provides insights into how the research field has developed over time and enables the identification of both early-stage studies and emerging research trends. In the visualization, the color gradient represents the average publication year of keywords, where blue indicates earlier research topics and yellow represents more recent developments. During the initial stage of research, keywords such as *"maize," "Zea mays," "grain," "biomass,"* and *"agriculture"* appear predominantly in blue. This indicates that early studies were primarily focused on the biological and physical characteristics of maize, including its structure and general agricultural aspects.

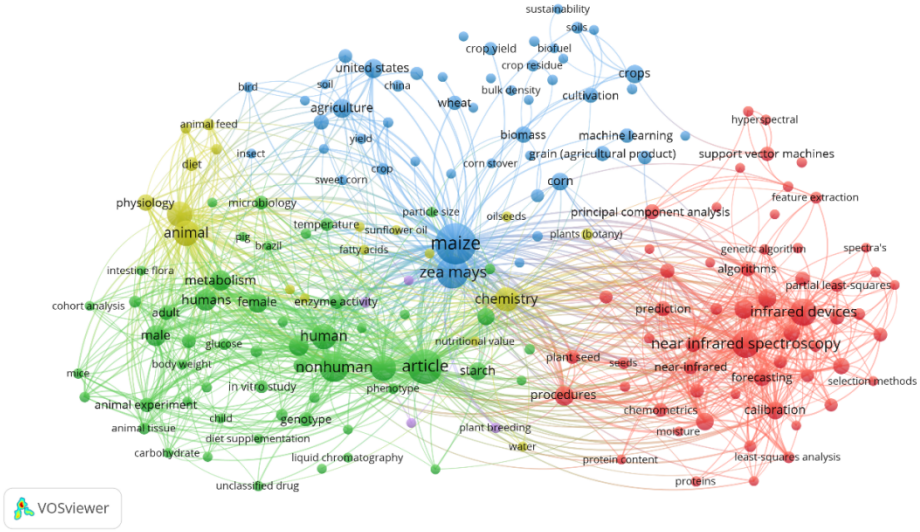


Figure 5. Keyword co-occurrence network in research on maize ear separation technologies based on VOSviewer.

In the intermediate stage (green color), keywords such as *"analysis," "quality," "plants,"* and *"chemistry"* emerge, reflecting a shift toward investigating material properties, chemical composition, and product quality [20,21]. This stage is characterized by a deeper focus on seed quality evaluation and the underlying mechanisms of separation processes [22]. In recent years, the appearance of keywords such as *"near-infrared spectroscopy," "machine learning," "algorithm," "prediction," "feature extraction,"* and *"selection methods"* in yellow and red indicates a transition to a new stage of

research. This phase is associated with the integration of sensor technologies, artificial intelligence, and data-driven approaches aimed at improving the accuracy of maize ear sorting and enhancing seed quality [23,24]. Overall, the overlay visualization demonstrates that the research field has evolved from fundamental biological and physical studies toward advanced, technology-driven, and intelligent systems. This transition highlights the increasing importance of precision agriculture and digital technologies in modern agricultural practices.

3.5. Temporal evolution of keywords in research on maize ear separation technologies

The visualization (Figure 6) illustrates the temporal evolution of keywords using a color gradient, where blue represents earlier research (around 2020–2022), green indicates intermediate stages, and yellow reflects the most recent research directions (2023–2024).

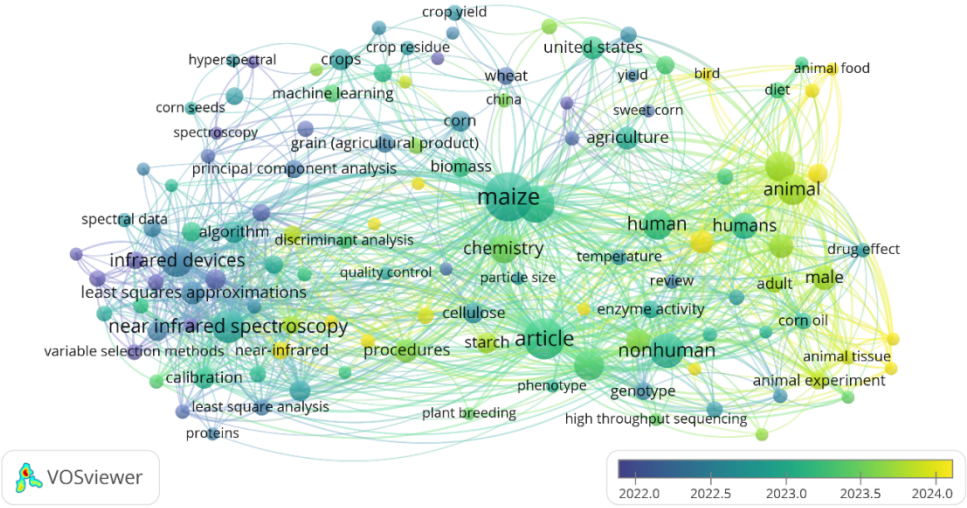


Figure 6. Temporal evolution of keywords in research on maize ear separation technologies.

According to the analysis, the keyword *"maize"* is positioned at the center of the network with the highest link strength, indicating its role as the core concept connecting all research activities in this field. Surrounding keywords such as *"agriculture," "grain," "biomass,"* and *"corn"* highlight that early studies were primarily focused on agricultural and biological characteristics [25]. On the left side of the network, keywords displayed in blue—such as *"infrared devices," "near-infrared spectroscopy," "least squares approximations,"* and *"principal component analysis"*—represent the initial technological stage of research. During this phase, the main focus was on determining the physical and chemical properties of maize and analyzing them using spectral methods [26,27].

On the right side, more recent keywords shown in yellow—such as *"machine learning," "algorithm," "prediction," "feature extraction,"* and *"calibration"*—indicate the emergence of advanced research directions [28,29]. These trends reflect the increasing application of artificial intelligence, data-driven approaches, and automated systems in the sorting and separation of maize ears [7,13,30]. Overall, the overlay visualization demonstrates that research on maize ear separation has evolved from traditional agronomic and laboratory-based analyses toward advanced, high-precision systems based on sensor technologies and artificial intelligence. This transition confirms the growing importance of precision agriculture and digital technologies in modern agricultural systems.

4. Conclusion

This study presents a bibliometric analysis of research on maize ear separation technologies for seed purposes based on the Scopus database. The results indicate a steady increase in scientific activity, highlighting the growing importance of this field in modern agriculture. Journal articles dominate the publication landscape, confirming the maturity and active development of this research

area. Geographically, scientific output is concentrated in leading countries such as China and the United States, reflecting their strong technological and research capacities.

Keyword analysis reveals a transition from traditional agronomic approaches to advanced technologies, including near-infrared spectroscopy, machine learning, and data-driven methods, indicating the rapid development of intelligent and automated systems. Despite this progress, limited research activity in certain regions suggests the existence of significant opportunities for future studies. In particular, the development of high-precision and efficient technologies for seed quality assessment and separation remains a key research priority. Overall, maize ear separation technologies are evolving toward modern, intelligent, and integrated systems, providing a strong scientific foundation for future advancements in this field.

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