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RESEARCH TRENDS IN EGGPLANT (*Solanum melongena* L.) BREEDING: A BIBLIOMETRIC STUDY

Samsul Ma'arif[1]*, Asifa[2], & Iskandar[3]
[1&2]Agribusiness Study Program, Faculty of Agriculture and Forestry, Satya Terra Bhinneka University, Sunggal Street Gg. Bakul, Medan, North Sumatra 20128, Indonesia
[3]Forestry Management Study Program, Faculty of Agriculture and Forestry, Satya Terra Bhinneka University, Sunggal Street Gg. Bakul, Medan, North Sumatra 20128, Indonesia
**Email: samsulmaarif@satyaterrabhinneka.ac.id*
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ABSTRACT: Eggplant (*Solanum melongena* L.) is an important horticultural crop with high economic and nutritional value. Climate change, environmental stress, and food security concerns have accelerated research on eggplant breeding worldwide.. However, comprehensive evaluations of research trends in eggplant breeding remain limited. Therefore, this study aimed to perform a bibliometric analysis of global eggplant breeding research published between 2016 and 2026. Data were collected from the Scopus database using the query Title-Abs-Key ((“eggplant” or “aubergine”) and (“plant breeding” or hybridization or cultivar or “hybrid variety”)). The analysis included English-language articles and was conducted using Bibliometrix/Biblioshiny and VOSviewer. A total of 562 documents were analyzed. The results showed that scientific publications increased substantially after 2019, indicating growing global interest in eggplant genetic improvement. China was the most productive country, with 117 publications and 2,124 citations, followed by the United States (35 publications), Spain (35 publications), and India (15 publications). Collaboration analysis demonstrated extensive international partnerships, whereas keyword and thematic analyses revealed dominant topics related to hybridization, disease resistance, stress tolerance, antioxidants, and molecular breeding. Recent studies have increasingly focused on abiotic stress, heterosis, and nutritional quality improvement. This study provides insights into research development and emerging trends in eggplant breeding research.

Keywords: Bibliometric Analysis, Collaboration Network, Eggplant Breeding, Molecular Breeding.

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INTRODUCTION

Eggplant (*Solanum melongena* L.) is one of the most important vegetable crops cultivated globally (Akanksha et al., 2023; Faizan et al., 2022; Ma'arif et al., 2025; Yang et al., 2023) because of its high nutritional value, economic importance, and adaptability to various agroecological conditions. Eggplant fruits contain essential nutrients, dietary fiber, vitamins, anthocyanins, and antioxidant compounds that contribute to human health and food security. The increasing demand for horticultural products requires continuous improvement in eggplant productivity and quality. However, eggplant production faces various constraints,

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including biotic stress caused by pests and diseases, as well as abiotic stress, such as drought, salinity, and extreme temperatures, which significantly reduce yield and fruit quality (Guru Prasad et al., 2025). Therefore, the development of superior eggplant varieties with high productivity and stress tolerance has become increasingly important in modern agricultural systems.

Plant breeding plays a major role in improving agronomic traits, environmental stress resistance, and fruit quality during eggplant cultivation. Conventional breeding approaches based on phenotypic selection and hybridization have been widely used to develop cultivars with desirable characteristics. In addition, the utilization of molecular markers, Quantitative Trait Loci (QTL) analysis, and genetic diversity studies have accelerated breeding efficiency and selection accuracy in eggplant breeding programs (Brozynska et al., 2016). Advances in genomics and biotechnology have further contributed to the identification of important genes associated with disease resistance, yield components, and fruit quality traits, thereby supporting the development of more efficient breeding strategies for these traits. These technological advances have substantially increased research activity in eggplant breeding in the past decade.

The rapid growth of publications related to eggplant breeding highlights the importance of bibliometric analysis in understanding research trends, collaboration networks, and emerging scientific topics. Bibliometric analysis is widely used to evaluate scientific development through publications, citations, authorship, and keyword relationships. Several bibliometric studies have been conducted in various agricultural fields to identify research patterns and future opportunities; however, no previous bibliometric study has systematically mapped global research trends, collaboration networks, thematic evolution, and emerging topics in eggplant breeding research. Furthermore, dominant research themes, influential authors, institutional collaborations, and emerging directions in eggplant breeding remain insufficiently explored topics.

Therefore, this study aimed to perform a bibliometric analysis of global research trends in eggplant breeding. This study aimed to identify publication trends, major contributing countries and institutions, influential journals and authors, collaboration networks, and emerging research topics in the field of eggplant breeding. These results provide insights into current research developments and future directions in eggplant breeding programs.

METHODS

This study employed a bibliometric approach to analyze global research trends in eggplant breeding. Bibliographic data were collected from the Scopus database, which is recognized as one of the largest and most comprehensive databases of scientific publications (Baas et al., 2020). Data collection was conducted in May 2026 using the following search query: Title-Abs-Key ((“eggplant” or “aubergine”) and (“plant breeding” or hybridization or cultivar or “hybrid variety”)). The initial search identified 1,038 documents in the Scopus database. The search results were subsequently refined by limiting the publication years (2016–2025), language (English), document type (research articles), and subject areas related to agricultural and biological sciences, as well as biochemistry,

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genetics, and molecular biology. Based on these criteria, 401 documents were retrieved and used for further bibliometric analysis. The overall workflow of data collection, screening, processing, and bibliometric analysis conducted in this study is presented in Figure 1.

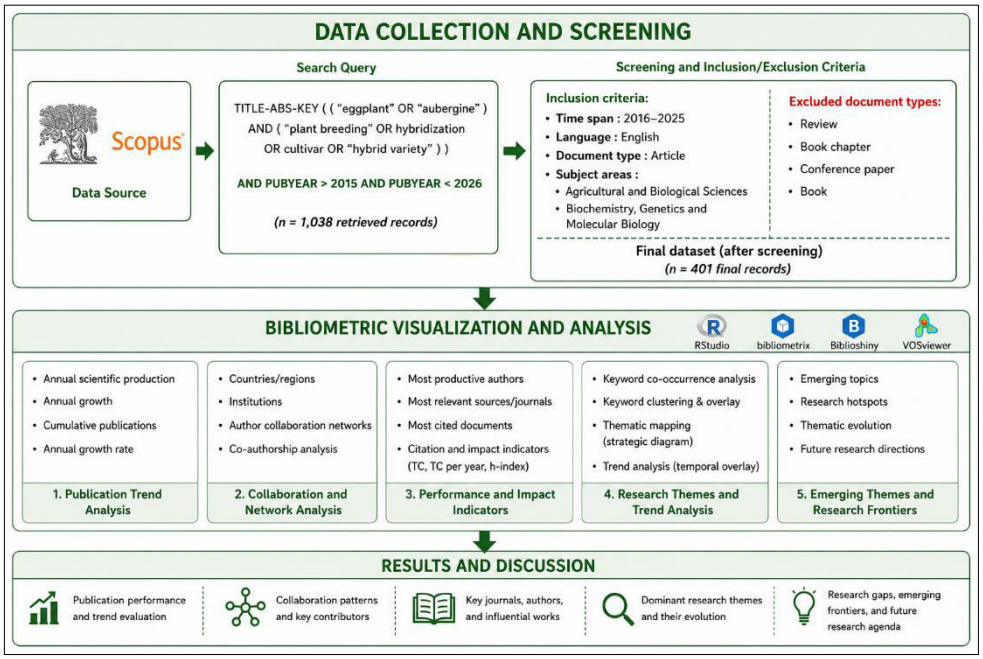

Figure 1. Workflow of Data Collection and Bibliometric Analysis.

Figure 1 illustrates the overall workflow of this study, including data collection, screening, data cleaning, bibliometric analysis, and visualization of research trends in eggplant breeding research. The retrieved data were exported from Scopus in CSV format and included information related to authors, titles, abstracts, keywords, affiliations, citations, and references. Prior to the analysis, the dataset was screened and cleaned using OpenRefine version 3.8. OpenRefine was used to identify duplicate records, standardize inconsistencies in author names and keywords, correct formatting variations, and remove irrelevant documents that were not directly related to eggplant breeding research. A data cleaning process was conducted to improve dataset accuracy, consistency, and reliability prior to bibliometric analysis and visualization.

The cleaned dataset was subsequently analyzed using the Bibliometrix package (version 4.3) and Biblioshiny interface in Rstudio version 2024.12 (Aria & Cuccurullo, 2017) to evaluate publication trends, citation structures, collaboration networks, and thematic development. Several bibliometric indicators were analyzed in this study, including annual scientific production, most influential documents, productive journals, contributing countries, collaboration networks, and keyword occurrence patterns. Keyword co-occurrence analysis and thematic mapping were further conducted to identify dominant research themes and emerging topics in eggplant breeding research.

Network visualization analyses were performed using VOSviewer version 1.6.20 (van Eck & Waltman, 2010) to examine the collaboration relationships

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among authors and countries and keyword co-occurrence patterns within the research field. In addition, Tableau 2026 was utilized to support graphical visualization and presentation of bibliometric indicators, publication trends, and country productivity.

RESULTS AND DISCUSSION

Annual Scientific Publication

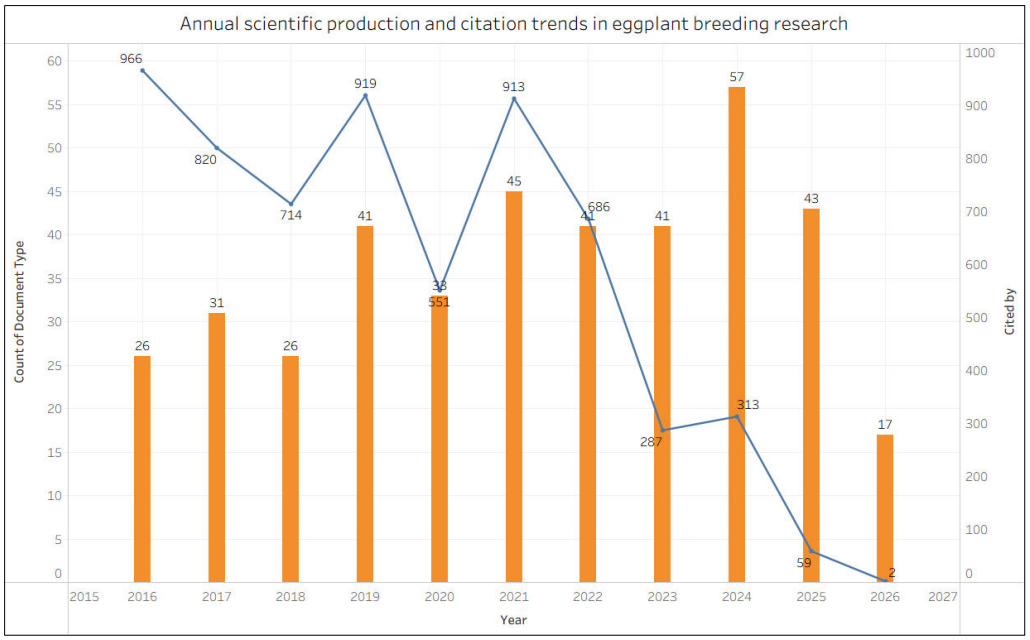

Figure 2. Annual Scientific Production and Citation Trends in Eggplant Breeding Research.

Figure 2 illustrates the annual scientific production and citation trends related to eggplant breeding research between 2016 and 2026. The annual publication trend demonstrated a fluctuating but generally increasing pattern during the observation period. The number of publications increased from 26 in 2016 to 41 in 2019, followed by a slight decline to 33 in 2020. Publication output subsequently increased again, reaching 45 documents in 2021 and peaking at 57 in 2024. However, publication output decreased to 43 documents in 2025 and 17 documents in 2026, which may be associated with incomplete indexing and the ongoing publication process for that year. These findings indicate a sustained growth in global research interest in eggplant breeding despite short-term fluctuations in annual publication output.

The increasing trend in publication growth reflects the expanding importance of eggplant breeding in modern agricultural practices. The demand for improved eggplant cultivars with higher productivity, enhanced fruit quality, and better tolerance to biotic and abiotic stresses has encouraged the development of breeding-related studies worldwide. In addition, advances in breeding technologies, including hybridization techniques, molecular breeding, genomic analysis, and biotechnology-assisted selection, have accelerated research activities and contributed to the increasing number of publications in this field. The broader

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availability of genomic resources and molecular tools has enabled researchers to explore more efficient breeding strategies to improve eggplant performance under changing environmental conditions.

The citation trend, represented by the cited-by indicator in Figure 2, showed substantial fluctuations throughout the observation period. The highest citation count was recorded in 2016 (966 citations), followed by 919 citations in 2019 and 913 citations in 2021. Several years exhibited remarkably high citation values despite relatively low publication numbers, indicating the presence of influential studies that became important references for subsequent research. In contrast, publications produced in 2025 and 2026 showed relatively lower citation values (59 and 2 citations, respectively), owing to limited citation accumulation time. These findings suggest that research conducted during these periods contributed significantly to the development of eggplant breeding, particularly in areas related to genetic improvement, hybrid development, stress tolerance, and molecular breeding approaches.

The discrepancy between publication quantity and citation impact indicates that scientific influence is not solely determined by the number of publications but also by the novelty, relevance, and long-term contribution of the research. Earlier publications generally accumulated higher citation values because they had longer exposure periods within the scientific community, whereas recent publications showed relatively lower citation counts owing to the limited citation accumulation time. Overall, the annual publication and citation trends demonstrate that eggplant breeding has become an increasingly active and evolving research field, with growing global scientific attention and expanding research contributions.

Most Relevant Sources

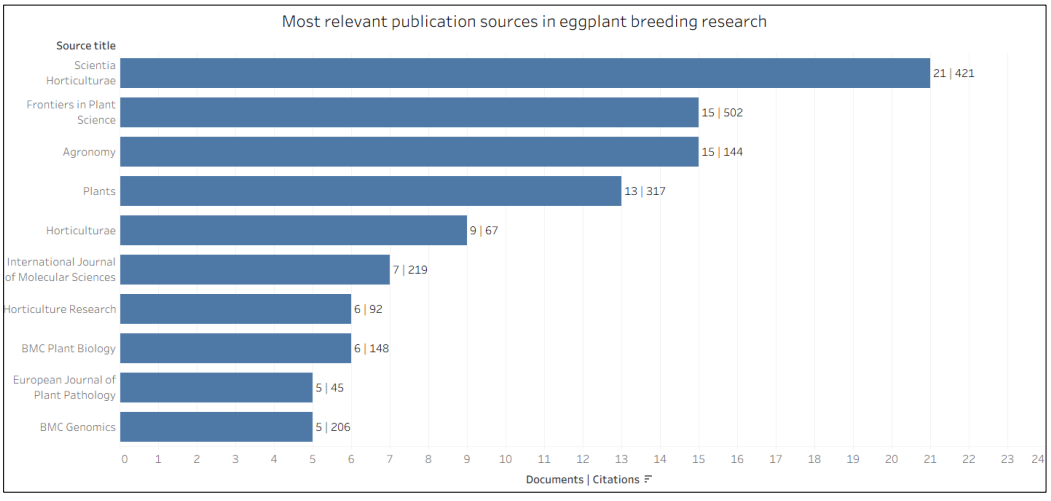

Figure 3. Most Relevant Publication Sources in Eggplant Breeding Research.

Figure 3 shows the most relevant publication sources that contributed to eggplant breeding research during the study period. The results showed that Scientia Horticulturae was the most productive source, with 21 published documents, followed by Frontiers in Plant Science and Agronomy, with 15 publications each. Plants, Horticulturae, International Journal of Molecular Sciences, Horticulture

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Research, BMC Plant Biology, European Journal of Plant Pathology, and BMC Genomics. The distribution of publications across various journals indicates that eggplant breeding research has attracted considerable attention from multidisciplinary scientific fields, particularly horticulture, plant science, genetics, agronomy, and biotechnology.

The dominance of horticulture-oriented journals, such as Scientia Horticulturae and Horticulturae, reflects the strong contribution of horticultural crop improvement studies in eggplant breeding research. In addition, journals such as Frontiers in Plant Science, International Journal of Molecular Sciences, BMC Plant Biology, and BMC Genomics indicate increasing research attention toward molecular and genomics-related studies in eggplant breeding. This distribution of publication sources demonstrates the multidisciplinary research scope of eggplant breeding studies involving horticulture, genetics, plant pathology, and biotechnology.

Several journals with relatively lower publication numbers have demonstrated high citation values, indicating strong scientific influence despite limited publication frequency. For example, Frontiers in Plant Science recorded 15 publications with 502 citations. Highly cited studies published in this journal include those by Hayat et al. (2016), which have accumulated 98 citations according to global citation analysis. Similarly, Scientia Horticulturae has accumulated 421 citations from 21 documents, including influential studies reported by Hannachi & Van Labeke, (2018) with 111 citations. Plants have also demonstrated considerable citation performance, accumulating 317 citations from 13 publications. In addition, the International Journal of Molecular Sciences contributed substantially through highly cited studies such as (Parisi et al., 2020), which recorded 122 citations. These findings indicate that journals related to plant science and molecular research contributed substantially to the scientific influence of eggplant breeding studies.

Most Influential Documents

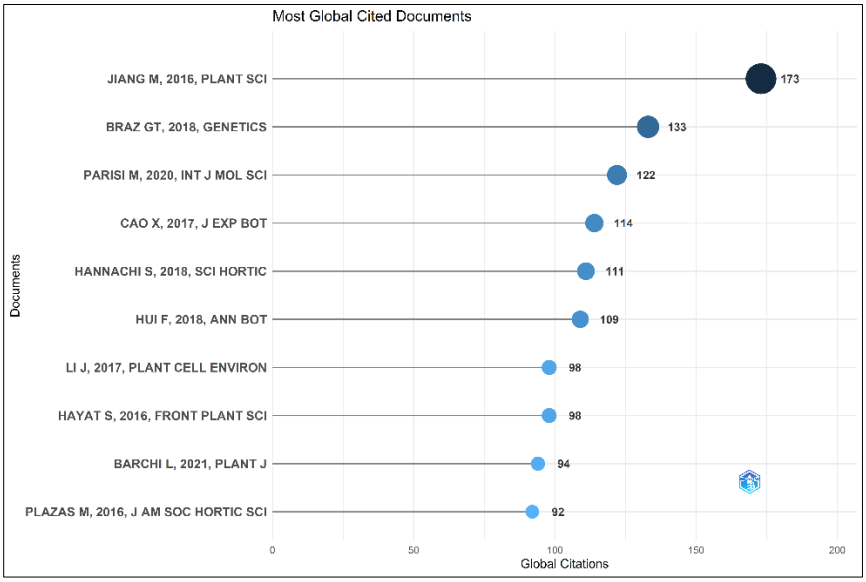

Figure 4. Most Globally Cited Documents in Eggplant Breeding Research Based on Citation Analysis.

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Figure 4 presents the most globally cited documents on eggplant breeding research based on citation performances. The results demonstrated that several highly cited studies have played important roles in shaping the development of modern eggplant breeding research, particularly in areas related to molecular genetics, stress tolerance, genomics, and improving crops.

The most influential document was published by Jiang et al. (2016) in Plant Science and has 173 citations. Other highly cited publications include those by Braz et al. (2018) in Genetics (133 citations), Parisi et al. (2020) in the International Journal of Molecular Sciences (122 citations), Cao et al. (2017) in the Journal of Experimental Botany (114 citations), and Hannachi & Van Labeke, (2018) in Scientia Horticulturae (111 citations). These studies were primarily associated with genetic analysis, genomics-assisted selection, and stress adaptation research in crop breeding.

Several influential studies have also been associated with disease resistance and physiological adaptation, as reflected by publications in journals such as the Journal of Experimental Botany, Scientia Horticulturae, Annals of Botany, and Frontiers in Plant Science. The strong citation performance of these studies indicates substantial research attention toward resistance breeding, stress physiology, and molecular characterization in eggplant breeding research. Additional highly cited studies include Hui et al. (2018) in Annals of Botany (109 citations), Li et al. (2017) in Plant Cell and Environment (98 citations), Hayat et al. (2016) in Frontiers in Plant Science (98 citations), Barchi et al. (2021) in Plant Journal (94 citations), and Plazas et al. (2016) in the Journal of the American Society for Horticultural Science (92 citations).

The distribution of highly cited publications across multidisciplinary journals further demonstrates the broad research scope of eggplant breeding studies, which involve genetics, biotechnology, plant physiology, and crop improvement research. Citation analysis also indicated that studies addressing widely applicable crop improvement challenges tend to demonstrate a stronger scientific influence within the research field.

Country Scientific Production

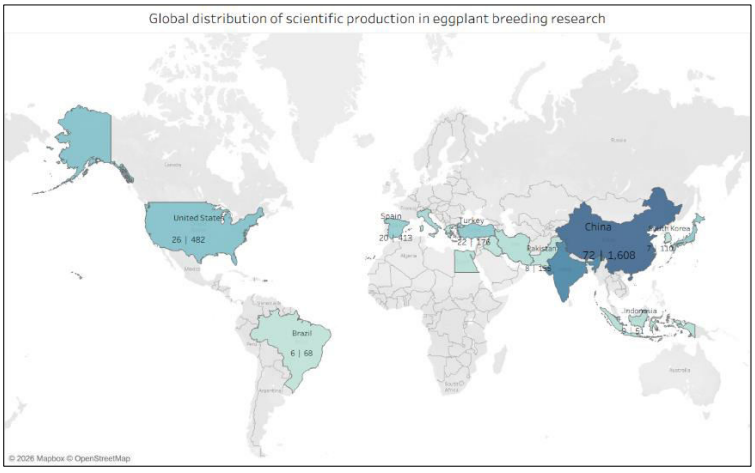

Figure 5. Global Distribution of Scientific Production in the Field of Eggplant Breeding Research.

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Figure 5 illustrates the global distribution of scientific production related to eggplant breeding research. The results demonstrated that research activities in this field are widely distributed across multiple regions, particularly in Asia, Europe, and North America. China emerged as the most productive country, with 72 published documents and 1,608 citations, indicating its dominant contribution and scientific influence on eggplant breeding research. Other major contributing countries included the United States (26 publications and 482 citations), Turkey (22 publications and 176 citations), Spain (20 publications and 413 citations), and Pakistan (8 publications and 155 citations). Several additional countries, including South Korea, Brazil, and Indonesia, have also contributed to eggplant breeding studies.

China's dominance in publication productivity may reflect the strategic importance of eggplants as a major horticultural crop in Asian agricultural systems. China is recognized as one of the largest producers and consumers of eggplant worldwide, which may have encouraged research on cultivar improvement, hybrid development, disease resistance, and yield enhancement in the country. In addition, the rapid development of biotechnology, genomics, and molecular breeding platforms in China has accelerated the scientific production of horticultural crop breeding. The exceptionally high citation value observed for China also indicates that many Chinese publications have become influential in subsequent breeding research.

European countries, such as Spain, have demonstrated strong research contributions, particularly in terms of their citation performance. Spain recorded 413 citations from 20 publications, suggesting a substantial scientific impact, despite lower publication numbers than China. This finding indicates that European research institutions have significantly contributed to advanced breeding approaches, including genetic diversity analyses, molecular marker development and stress tolerance studies. Similarly, the United States exhibited a strong scientific influence with 482 citations, reflecting the active integration of genomics, biotechnology, and molecular breeding technologies into eggplant improvement programs.

Several developing countries, including Pakistan, Indonesia, Brazil, and Turkey, have contributed to eggplant breeding research; however, their publication productivity and citation performance remain relatively low. The increasing participation of these countries may be associated with the growing importance of eggplant as a food security crop in the tropical and subtropical regions. In many developing countries, eggplants are widely cultivated owing to their adaptability, nutritional value, and economic importance for smallholder farming systems. Consequently, breeding programs focusing on stress tolerance, pest resistance, and yield improvement have become increasingly important for supporting sustainable vegetable production.

The global distribution of scientific production demonstrates that eggplant breeding has evolved into an internationally collaborative and multidisciplinary field. The concentration of publications in Asia, Europe, and North America reflects the major production centers and technological advancements in horticulture crop breeding. Furthermore, the variation in publication productivity and citation impact

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among countries suggests differences in research capacity, technological infrastructure, funding availability and international collaboration networks. Overall, the results indicate that eggplant breeding research continues to expand globally, driven by the increasing demand for improved cultivars and sustainable agricultural systems under changing environmental conditions in the future.

Collaboration Network Analysis

Country Collaboration Network

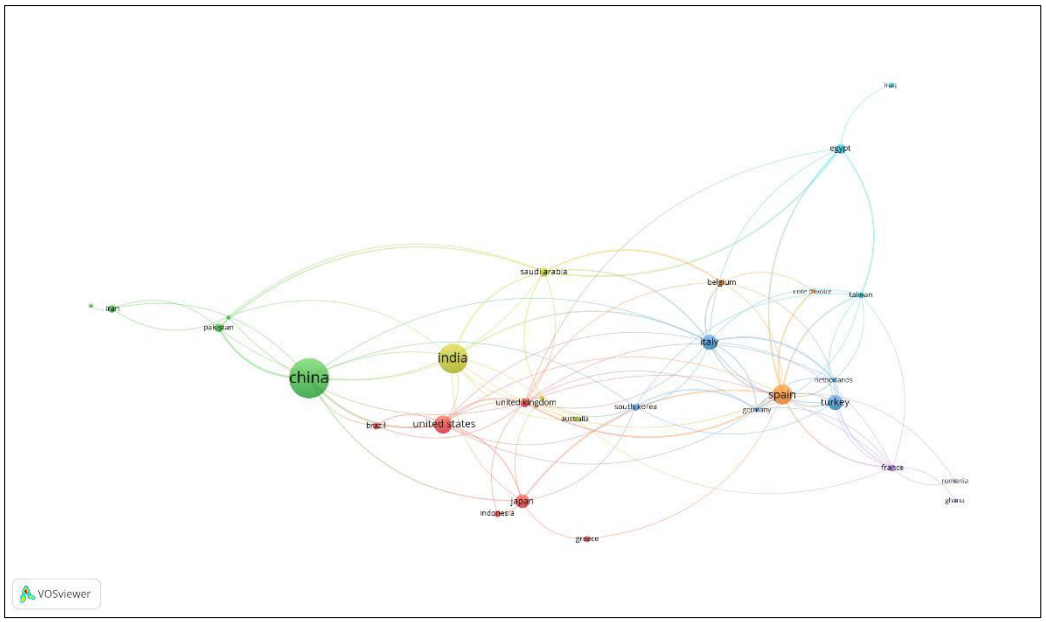

Figure 6. International Collaboration Network in Eggplant Breeding Research Based on Country Co-Authorship Analysis.

Figure 6 presents the international collaboration network in eggplant breeding research based on co-authorship relationships among countries. The visualization demonstrates that eggplant breeding research has developed through extensive international collaboration involving countries in Asia, Europe, North America, South America, and Africa. Several countries occupy central positions within the collaboration network, indicating their important roles in connecting global research activities. China, India, Italy, the United States, and the United Kingdom appeared as major collaboration hubs with extensive intercountry connections and relatively large node sizes, reflecting high publication productivity and strong collaborative influence in this research field.

China demonstrated one of the strongest collaboration networks, particularly with Pakistan, India, Saudi Arabia, and the United States. Strong collaborative relationships were also observed between China and Iran, Thailand, and Poland. The strong collaboration observed among Asian countries may be associated with the importance of eggplant as a major vegetable crop in Asian agricultural systems. In addition, many Asian countries share similar environmental conditions, pest challenges, and breeding objectives, encouraging collaborative studies on stress tolerance, disease resistance, and cultivar improvement. Collaboration between China and developed countries, such as the United States,

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suggests increasing integration between conventional breeding programs and advanced molecular breeding technologies. These international partnerships are likely to accelerate knowledge exchange, facilitate the development of improved eggplant cultivars, and strengthen global research capacity to address emerging agricultural challenges.

Spain has emerged as an important collaboration center, connecting multiple countries in Europe, Asia, and Latin America. Strong collaborative relationships were observed between Spain and countries such as Italy, Turkey, Germany, Egypt, Taiwan, Belgium, and the Netherlands. Spain's central role in the network indicates the substantial contribution of European research institutions to international horticultural breeding programs. European collaborations are generally characterized by multidisciplinary approaches involving genetics, biotechnology, molecular biology, and crop improvement. The extensive connectivity of Spain also suggests active participation in international research projects and scientific partnerships related to horticultural crop breeding.

The United States has demonstrated broad collaboration patterns with countries in multiple regions, including Japan, South Korea, Brazil, Australia, and the United Kingdom. This finding reflects the important role of the United States in advancing biotechnology- and genomics-based breeding research in the past. Several collaborative links involving the United States may also indicate the exchange of genomic resources, breeding materials, and advanced analytical technologies among research institutions. Similarly, India has shown strong interactions with several Asian and European countries, reflecting its growing contribution to vegetable crop breeding and food security research in tropical agricultural systems.

Network visualization further revealed the presence of several regional collaboration clusters. For example, France and Romania formed smaller interconnected collaboration networks with Spain and Turkey, whereas Middle Eastern countries, such as Saudi Arabia, Egypt, and Iraq, demonstrated active collaboration links with Asian and European countries. These collaborations may reflect international efforts to improve vegetable crop productivity and resilience through technology transfer and collaborative breeding programs. In addition, collaboration links involving African countries, such as Ghana and Côte d'Ivoire, indicate increasing international interest in horticultural crop improvement in developing regions.

The collaboration network further demonstrated that scientific advancements in eggplant breeding increasingly depend on international partnerships and multidisciplinary cooperation. Collaborative interactions among countries facilitate the exchange of breeding materials, genomic resources, advanced analytical technologies, and scientific expertise, thereby accelerating innovation in cultivar development and stress-adaptation strategies. The expanding global collaboration observed in this study indicates that future eggplant breeding research will likely continue to move toward more integrated and internationally connected research systems in response to agricultural and environmental challenges. Strengthening these collaborative networks will be essential for ensuring sustainable genetic improvement and global food security.

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Author Collaboration Network

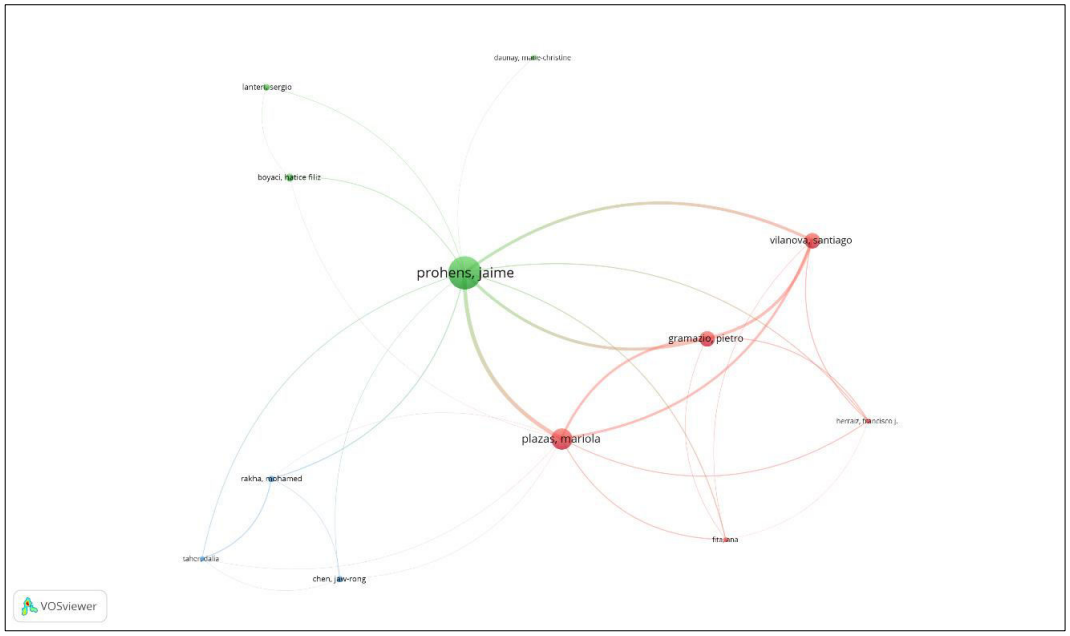

Figure 7. Author Collaboration Network in Eggplant Breeding Research Based on Co-Authorship Analysis.

Figure 7 presents the author collaboration network in eggplant breeding research based on the co-authorship analysis. The visualization demonstrates that scientific collaboration in this field is organized into several interconnected research clusters involving authors with strong collaborative relationships. The formation of these clusters indicates that eggplant breeding research has increasingly developed through teamwork and multidisciplinary cooperation, rather than individual research activities. Several authors occupied central positions within the network and acted as important connectors between research groups, reflecting their substantial contributions to scientific communication and collaborative publication activities.

The network structure shows that authors from Europe dominated the collaboration landscape, particularly researchers from Spain and Italy, which reflects the strong contribution of European institutions to eggplant breeding research. Several closely connected clusters involving authors, such as Jaime Prohens, Mariola Plazas, Santiago Vilanova, Pietro Gramazio, and Hatice Filiz Boyaci, demonstrated strong internal collaboration patterns. These findings suggest that many eggplant breeding studies are conducted through institutional and national research groups with continuous collaborative interactions. In addition, the strong connectivity among authors may indicate long-term research partnerships focusing on specific topics, such as hybrid breeding, stress tolerance, molecular genetics, and disease resistance.

Among the identified clusters, the group centered around Jaime Prohens appeared to function as one of the main connecting nodes linking multiple collaboration groups. Strong collaborative links were observed between Jaime

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Prohens and Mariola Plazas, indicating their important roles in bridging different research themes and facilitating scientific integration among breeding, molecular biology, and biotechnology studies. Similarly, the close collaboration observed among the authors within the Mariola Plazas, Santiago Vilanova, and Pietro Gramazio clusters suggests active cooperation in genomics-assisted breeding and advanced molecular research. The dense interaction among the authors further reflects the increasing complexity of eggplant breeding research, which often requires integrated expertise from multiple scientific disciplines.

The existence of relatively separate clusters also indicates specialization among research groups. For example, the cluster involving Mohamed Rakha, Dalia Taher, and Jaw-rong Chen formed a smaller interconnected collaboration group, whereas another cluster involving Hatice Filiz Boyaci and Sergio Lanteri demonstrated independent collaborative interactions connected through Jaime Prohens. Some author groups appeared to focus more strongly on molecular and genomic studies, whereas others were more closely associated with conventional breeding, cultivar development, or stress resistance research. This clustering pattern demonstrates that eggplant breeding research has diversified into several specialized subfields while remaining interconnected through broader collaborative networks.

The author collaboration network further highlights the increasing importance of cooperative research in accelerating scientific development within eggplant breeding programs. Strong co-authorship relationships facilitate knowledge exchange, resource sharing, and methodological integration among researchers from diverse institutions and scientific backgrounds. Such collaborative interactions may substantially contribute to the advancement of breeding technologies, molecular-assisted selection, and sustainable crop improvement strategies for future horticultural production.

Keyword Co-occurrence Analysis

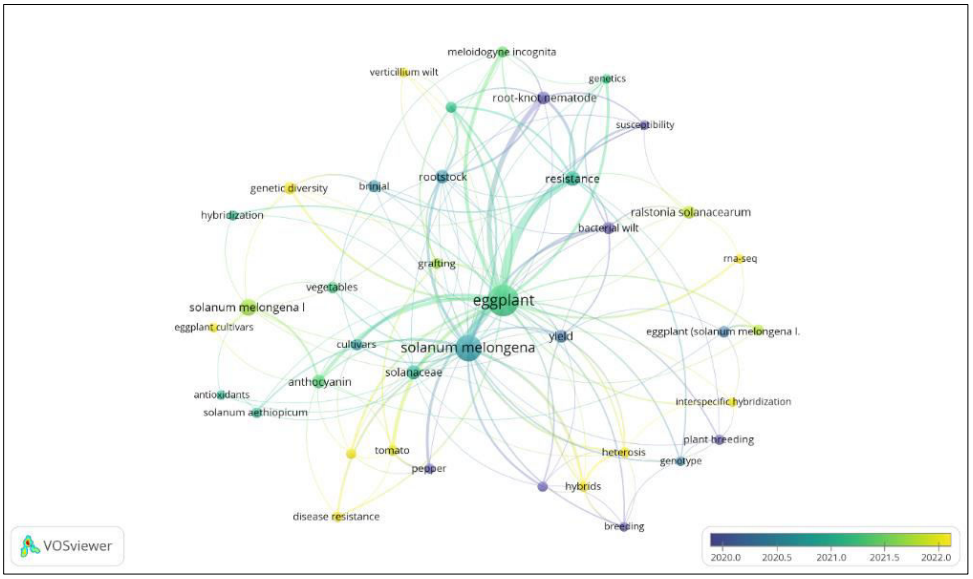

Figure 8. Keyword Co-Occurrence Network in Eggplant Breeding Research Based on Author Keywords.

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Figure 8 shows the keyword co-occurrence network in eggplant breeding research based on author keywords. The visualization demonstrates that the research field has developed through interconnected themes involving conventional breeding, molecular genetics, stress resistance, biotechnology, and crop improvement strategies. The keywords "eggplant" and "*Solanum melongena*" appeared as the central nodes with the highest connectivity, indicating their dominant role in linking multiple research topics within the scientific network. The dense interconnections among keywords further suggest that eggplant breeding research has evolved into a multidisciplinary field integrating horticulture, genetics, molecular biology, plant pathology, and biotechnology approaches.

Several major thematic clusters were identified in the network. One important cluster was associated with breeding and hybridization-related topics, represented by keywords such as "breeding", "hybrids", "heterosis", "interspecific hybridization", "plant breeding", and "cultivar". This cluster reflects a strong emphasis on developing superior eggplant cultivars through hybrid breeding strategies and genetic improvement programs. The occurrence of "heterosis," "hybridization, "and "interspecific hybridization" also indicates increasing research interest in utilizing genetic variation from related *Solanum* species to improve agronomic traits and stress tolerance in eggplant breeding programs.

Another major cluster was associated with disease resistance and stress-related studies, represented by keywords such as "disease resistance", "biotic stress", "resistance", "Verticillium wilt", "bacterial wilt", "root-knot nematode", and "Ralstonia solanacearum". The prominence of these keywords suggests that resistance breeding has become an important component of eggplant improvement research. The strong relationship between resistance-related keywords and terms such as "rootstock" and "grafting" further indicates the increasing integration of plant pathology and molecular breeding approaches in eggplant breeding studies.

The network also revealed substantial research attention toward molecular and genomic approaches, represented by keywords such as "genetics", "genotype", "RNA-seq", and "genetic diversity". These findings indicate an increasing integration of genomics-assisted breeding and molecular characterization approaches in eggplant breeding research. Similarly, the occurrence of "genetic diversity" highlights the importance of germplasm evaluation in broadening the genetic base of breeding materials. In addition, several keywords related to nutritional quality and functional compounds, including "anthocyanin" and "antioxidants", were identified within the network. Additional keywords, such as "*Solanum aethiopicum*", "tomato", and "pepper", further suggest the utilization of related *Solanum* species and comparative crop studies in breeding and resistance research. This finding indicates increasing scientific interest in improving the nutritional and functional value of eggplant fruit in breeding research.

The overlay visualization further demonstrates the temporal evolution of research themes in eggplant breeding. More recent keywords, represented by yellow nodes, include "genetic diversity", "RNA-seq", "eggplant cultivars", "disease resistance", "heterosis", and "interspecific hybridization", indicating emerging research attention toward stress adaptation, molecular characterization, and advanced breeding strategies in eggplants. In contrast, earlier studies were more

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strongly associated with conventional breeding, disease resistance, and grafting-related methods. These findings suggest a gradual transition from conventional breeding to more integrated molecular and biotechnology-assisted breeding strategies.

Thematic Mapping and Trend Topics

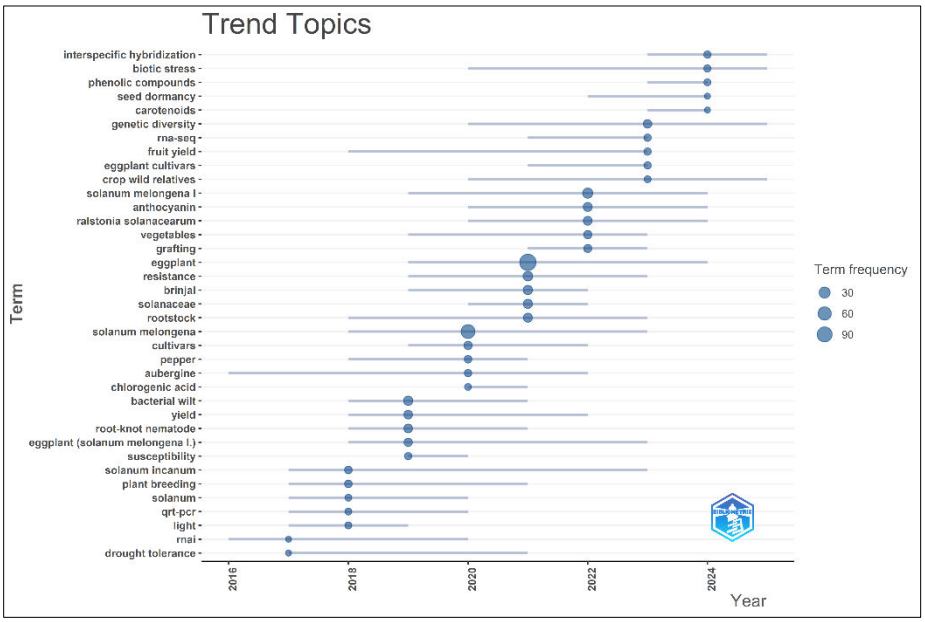

Figure 9. Trend Topic Analysis of Eggplant Breeding Research.

Figure 10. Thematic Map of Research Themes in Eggplant Breeding Studies.

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Temporal evolution and trend topic analyses provided a broader overview of the development and transformation of research themes in eggplant breeding over time. Figure 9 illustrates the temporal evolution of research topics, and Figure 10 presents a thematic map based on the centrality and density values. These analyses demonstrated that eggplant breeding research has progressively shifted from conventional breeding approaches to more integrated studies involving stress adaptation, biotechnology, nutritional quality, and molecular-assisted breeding strategies.

The trend topic analysis revealed that earlier studies between 2016 and 2019 were predominantly associated with keywords such as "drought tolerance", "RNAi", "qRT-PCR", "light", "plant breeding", "*Solanum incanum*", "susceptibility", "root-knot nematode", "yield", and "bacterial wilt". These findings indicate that initial research efforts were strongly focused on disease resistance, stress physiology, molecular detection techniques, and conventional breeding approaches aimed at improving breeding efficiency. During this period, conventional breeding and resistance evaluation remained important research priorities because soilborne diseases and pest infestations represented major production constraints in eggplant cultivation systems.

Beginning in 2020, the research landscape gradually expanded toward broader genetic and breeding-related topics, including "cultivar", "*Solanum melongena*", "eggplant", "rootstock", "Solanaceae", "brinjal", "resistance", "grafting", "vegetables", "anthocyanin", "crop wild relatives", "eggplant cultivars", "fruit yield", "RNA-seq", and "genetic diversity". These keywords indicate increasing research attention toward comparative Solanaceae studies, genetic characterization, and nutritional quality improvements. The emergence of terms such as "grafting", "rootstock", and "crop wild relatives" further reflects the increasing scientific interest in improving stress adaptation and productivity through integrated breeding and cultivation strategies. Similar trends related to hybrid breeding and heterosis utilization have been reported in horticultural crop improvement studies, particularly for enhancing yield performance, plant growth, and stress tolerance (Kumar et al., 2020; Yu et al., 2021).

Recent trends observed between 2023 and 2025 include "biotic stress", "interspecific hybridization", "phenolic compounds", "seed dormancy", and "carotenoids", indicating an increasing research emphasis on stress adaptation, nutritional quality, and advanced hybridization strategies. This trend is consistent with previous studies reporting increasing global research attention toward stress adaptation and climate-resilient crop breeding under changing environmental conditions. The thematic map further demonstrates the structural organization and maturity of research themes in eggplant breeding. The upper-right quadrant, representing motor themes, included keywords such as "*Solanum melongena* L." "anthocyanin", "cultivars", "flavonoids", and "disease resistance". These themes exhibited both high centrality and density, indicating that they are well-developed and highly influential within the research field. The prominence of anthocyanin-, flavonoid-, and cultivar-related themes further suggests increasing research interest in fruit quality, antioxidant compounds, and functional characteristics in eggplant breeding research (Lyu et al., 2025; Sharma & Katoch, 2024).

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The lower-right quadrant, representing basic themes, included keywords such as “eggplant”, “resistance”, “bacterial wilt”, “brinjal”, “root-knot nematode”, “*Solanum melongena*”, “yield”, “rootstock”, “*Solanum torvum*”, and “grafting”. These themes exhibited high centrality but relatively low density, indicating that they serve as fundamental and broadly connected topics in eggplant breeding research. The occurrence of “*Solanum torvum*” and “rootstock” highlights the importance of grafting technology and wild relatives in improving stress resistance and cultivation performance in breeding programs (Oladosu et al., 2021).

Meanwhile, the upper-left quadrant, representing niche themes, contained topics such as “plant breeding”, “interspecific hybridization”, “antioxidants”, “proline”, “drought”, “transcriptome”, “RNA-seq”, “qRT-PCR”, and “light”. These themes demonstrated relatively high development but lower connectivity to the broader research network. This finding indicates specialized research attention toward molecular biology, stress physiology, and transcriptomic analysis within eggplant breeding research, particularly studies related to salinity tolerance, genetic diversity analysis, and SSR-based characterization in eggplant germplasm and breeding materials (Suarez et al., 2021). In contrast, the lower-left quadrant representing emerging or declining themes was relatively less populated, suggesting that most current eggplant breeding studies are increasingly concentrated on well-established and interconnected research themes rather than isolated topics.

Overall, thematic mapping and trend topic analyses demonstrated that eggplant breeding research has evolved substantially over the past decade. Research trends have gradually shifted from conventional breeding and disease resistance studies toward integrated approaches involving genomics, stress adaptation, nutritional quality enhancement, and advanced hybrid breeding technologies. These findings indicate that future eggplant breeding programs will increasingly depend on multidisciplinary approaches integrating molecular biology, biotechnology, stress physiology, and sustainable agricultural innovation to address future food production and environmental challenges.

Research Gaps and Future Research Directions

Although publications related to eggplant breeding have increased substantially over the past decade, several research gaps remain. A bibliometric analysis revealed that most studies were dominated by conventional breeding approaches, hybridization, disease resistance, and cultivar development. Keyword and thematic analyses further demonstrated strong research concentrations on resistance breeding, grafting, rootstock utilization, and yield improvement, whereas advanced integrative breeding systems remain relatively underexplored. In contrast, the integration of molecular breeding and advanced genomic approaches into practical breeding programs remains limited. This indicates that eggplant breeding research is transitioning from conventional phenotype-based selection toward more comprehensive genomics-assisted breeding systems.

The thematic and trend topic analyses also demonstrated that stress-related studies, particularly abiotic stress and climate adaptation, have become more prominent only in recent years. Emerging trend topics such as “biotic stress”, “drought tolerance”, “phenolic compounds”, “carotenoids”, and “seed dormancy”

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indicate increasing scientific attention toward environmental adaptation and fruit quality improvement. This finding suggests that breeding research focusing on drought tolerance, salinity tolerance, and heat stress adaptation remains insufficient, despite increasing environmental challenges affecting vegetable production systems worldwide. Most previous studies primarily focused on disease resistance and yield improvement; in contrast, integrated studies combining stress physiology, molecular genetics, and breeding strategies are still relatively limited.

Another important gap identified in this study is the relatively low utilization of advanced omics technologies in eggplant breeding research. Although transcriptome analysis, RNA-seq, and genetic diversity studies have begun to emerge, the application of genomic selection, machine learning, artificial intelligence, and predictive breeding approaches remains rare in this field. Compared to major cereal crops, the implementation of high-throughput genomics and data-driven breeding strategies in eggplant research is underdeveloped. Consequently, future studies should focus on integrating genomics, bioinformatics, and artificial intelligence to accelerate breeding efficiency and improve the accuracy of selection.

Collaboration network analysis further revealed that scientific collaboration remains concentrated among a limited number of countries, particularly China, India, Spain, and the United States. However, despite the importance of eggplant as a major horticultural crop in tropical and subtropical regions, contributions from many developing countries remain relatively low. This finding highlights the need to strengthen international collaboration, research infrastructure, and technology transfer to support breeding innovations in developing agricultural systems.

The increasing emergence of keywords related to antioxidants, anthocyanins, flavonoids, and nutritional quality also demonstrate a shift in breeding objectives beyond productivity improvement alone. Modern breeding programs are increasingly expected to produce cultivars with enhanced nutritional value, functional compounds, and environmental adaptability. However, studies integrating nutritional quality improvement with stress resistance and yield stability are relatively scarce, indicating an important direction for future breeding research. Similarly, the increasing appearance of keywords such as “crop wild relatives”, “*Solanum torvum*”, “rootstock”, and “grafting” suggests growing scientific interest in utilizing wild germplasm and alternative cultivation strategies to improve stress resistance and productivity.

Future eggplant breeding research will likely continue to move toward integrated multidisciplinary approaches involving molecular breeding, biotechnology, genomics, stress physiology, and sustainable agriculture. The utilization of wild relatives, advanced hybrid breeding systems, genomic-assisted selection, and AI-based predictive breeding models may provide promising opportunities for developing superior eggplant cultivars with improved productivity, resistance, and nutritional quality under changing environmental conditions. Furthermore, strengthening international collaboration and expanding the use of high-throughput phenotyping and multi-environment testing will accelerate the development of climate-resilient eggplant cultivars that meet future agricultural and consumer demands.

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CONCLUSION

This bibliometric study demonstrated that research related to eggplant breeding has increased substantially over the past decade, particularly after 2019, which may reflect the growing importance of eggplant breeding in addressing productivity, stress tolerance, and nutritional quality challenges under changing environmental conditions. China, India, Spain, Italy, and the United States have emerged as major contributors to scientific production and international research collaboration. Keyword co-occurrence analysis, thematic mapping, and trend topic analyses revealed that eggplant breeding research has increasingly integrated molecular biology, genomics, biotechnology, and stress physiology approaches alongside conventional breeding strategies. Thematic evolution and keyword trend analyses identified emerging research directions related to interspecific hybridization, biotic stress, phenolic compounds, carotenoids, genetic diversity, crop wild relatives, anthocyanins, rootstock utilization, and grafting systems. The thematic map analysis further demonstrated that topics related to cultivars, flavonoids, anthocyanins, disease resistance, yield improvement, and *Solanum melongena* L. Have become important and well-developed research themes within eggplant breeding studies.

The findings also indicate that the integration of advanced omics technologies, artificial intelligence, and predictive breeding approaches remains relatively limited, highlighting important opportunities for future research development. This study presents a comprehensive bibliometric mapping analysis of global eggplant breeding research by identifying publication trends, collaboration networks, thematic evolution, and emerging research priorities that may support future breeding strategies and scientific collaboration programs.

SUGGESTION

Future research on eggplant breeding should focus on integrating advanced omics technologies, artificial intelligence, and predictive breeding approaches to accelerate the development of high-yielding, stress-tolerant, and nutritionally improved cultivars. Greater international collaboration and the utilization of crop wild relatives, interspecific hybridization, and grafting systems are also recommended to enhance genetic diversity and strengthen breeding programs under changing climate conditions. However, limitations such as unequal research capacity among countries, restricted access to genomic resources and advanced technologies, inconsistencies in bibliometric databases, and limited interdisciplinary collaboration may affect the comprehensiveness and future progress of eggplant breeding research.

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