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PAPER

Knowledge Map Analysis of Research Hotspots and Frontiers in Chinese Blueberry Quality from a CNKI Perspective (2004–2025)

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ABSTRACT

This study aims to systematically explore the knowledge map and development trends of blueberry quality research in China using bibliometric and knowledge mapping approaches. By analyzing 500 relevant articles from the China National Knowledge Infrastructure (CNKI) database (2004–2025), a multi-dimensional visualization was conducted using CiteSpace software. The findings show that the volume of publications on blueberry quality research in China has increased steadily and reached a phase of stabilization. Four core research clusters were identified: quality analysis and evaluation, postharvest storage and preservation technology, processing technology and product development, and variety resources and cultivation physiology. The research hotspots have evolved over time, starting with basic quality characterization and progressing to the exploration of functional components such as anthocyanins, optimization of postharvest technologies, and more recently, a focus on deep processing, flavor quality, molecular mechanisms, and intelligent control techniques. Prominent institutions, such as Jilin Agricultural University, play a leading role, though greater cross-institutional collaboration is needed. A relatively mature knowledge framework for blueberry quality research has been established in China. Moving forward, efforts should focus on enhancing interdisciplinary integration, investigating the mechanisms behind functional components, precisely regulating quality formation, and accelerating the translation of research outcomes into industrial applications. These efforts will provide a scientific foundation and strategic direction for the sustainable and healthy development of China's blueberry industry.

KEYWORDS

blueberry, quality, CiteSpace, research hotspots, development trends

1 INTRODUCTION

Blueberries (Vaccinium spp.), belonging to the family Ericaceae, are renowned as the "king of berries" and have been designated by the Food and Agriculture

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Organization of the United Nations (FAO) as one of the top five healthy foods for humans. This is due to their richness in bioactive compounds such as anthocyanins, phenolic acids, vitamin C, and organic acids, which provide numerous physiological benefits, including exceptional antioxidant and anti-inflammatory properties, improved vision, and cardiovascular protection [1].

In recent years growing health awareness and evolving consumer habits in China have fueled a strong demand for fresh blueberries and their processed products, leading to the rapid expansion of the domestic blueberry industry. China's blueberry cultivation area and production volume are now among the highest in the world, forming a complete industry chain that encompasses breeding, cultivation, storage, processing, and sales [2].

Blueberry quality is a core determinant of its commercial value, market competitiveness, and consumer acceptance. It is a multi-dimensional concept that includes external attributes (size, color, and firmness), flavor (sugar-acid ratio and aroma compounds), nutritional value (anthocyanins, vitamins, and minerals), and its suitability for storage and processing. Research aimed at improving and maintaining blueberry quality has garnered increasing attention, involving a range of disciplines such as horticulture, food science and engineering, plant physiology, and biochemistry and molecular biology. Prior studies have demonstrated that factors like variety, cultivation practices, harvest maturity, storage conditions, and processing methods can all significantly influence blueberry quality. For instance, a systematic study on the quality changes of different blueberry varieties during fruit development provided a basis for timely harvesting and variety selection [3]. Other researchers have explored the preservation effects of combined plasma-activated water and pulsed electric field treatments, offering a new direction for the development of novel preservation technologies [4].

Despite the substantial research achievements, existing studies often focus on specific aspects or single factors, lacking a macro-level understanding and systematic review of the field's overall development, knowledge structure, and evolving research hotspots. While some bibliometric analyses have addressed specific topics, such as anthocyanin research [5], a systematic knowledge map study focused on the comprehensive theme of "blueberry quality" has been rare. This study addresses this gap by providing a holistic overview of the field's evolution and structure.

2 MATERIALS AND METHODS

2.1 Data collection

The data for this study was sourced from the China National Knowledge Infrastructure (CNKI) database. An advanced search was conducted using the subject terms "blueberry" AND "quality" (in Chinese) with search fields including "title," "abstract," and "keywords." The document type was limited to "journal articles," and conference abstracts, news reports, non-core journal articles, and articles without author information were excluded to ensure the academic rigor and representativeness of the dataset. The specific inclusion/exclusion criteria were: Excluded: conference abstracts, news reports, and non-academic journal articles; Included: journal articles and peer-reviewed publications with complete author information [6]. The time span was set from January 1, 2004, to May 31, 2025. Since 2025 has not yet ended, the data for 2025 only represents partial or predicted data. To further guarantee data quality, the search results underwent manual screening to exclude news reports, conference notices, achievement introductions, non-academic literature, and articles without authors. The data cleaning process included using Refworks software to deduplicate the dataset; filtering out low-quality documents based on keywords, authors, and journal quality to ensure academic rigor and research value; and excluding incomplete or inaccurate documents to ensure the accuracy and reproducibility of the final dataset [7]. A final collection of 500 valid documents was obtained for analysis. All document information was exported in Refworks format for processing and deduplication using CiteSpace software [8].

2.2 Bibliometric analysis

The bibliometric visualization analysis was performed using CiteSpace 6.2.R4 (64-bit) software. The main parameters were set as follows: a time slicing of one year, with node types selected as Keyword, Author, and Institution. The selection criteria for thresholding utilized the Top N% or g-index algorithm to ensure the legibility and representativeness of the resulting maps [9].

3 RESULTS AND ANALYSIS

3.1 Annual publication trends

The analysis of the 500 blueberry quality research articles published between 2004 and 2025 in the CNKI database reveals an overall "S"-shaped growth curve in publication volume (see Figure 1), which distinctly illustrates the different developmental stages of the research field [9].

- Initial Exploratory Phase (2004–2010): During this period, the average annual publication volume was fewer than 10 papers, indicating that the field was in its nascent stage with relatively low research interest [10].
- Rapid Growth Phase (2011–2021): The number of publications surged from 15 in 2011 to nearly 60 in 2021, with an average annual growth rate exceeding 15%. This significant increase is strongly correlated with the rapid expansion of China's blueberry industry and the sharp rise in market demand for high-quality blueberries, which stimulated increased scientific investment [10].
- Stable Development Phase (2022 onwards): The research field entered a period of steady development. Publication volume peaked at approximately 65 papers in 2022 and, despite a slight decline, has since stabilized at around 50–60 papers per year. This trend suggests that the fundamental theoretical framework of blueberry quality research has been established, with research directions now shifting toward more in-depth mechanistic studies or specialized applications [11].

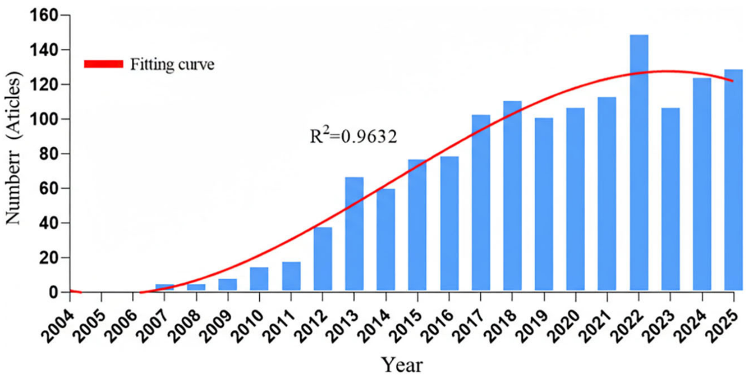

Fig. 1. Changes in the number of publications from 2004 to 2025

3.2 Keyword co-occurrence analysis

Keywords are the concentrated essence of a document's core content [12]. A keyword co-occurrence network reveals the hot topics within a research domain [13]. A co-occurrence network was constructed using keywords with a frequency of five or more. The results show that the central nodes in the network are "blueberry" (frequency 280, centrality 0.25), "quality" (frequency 220, centrality 0.18), "anthocyanins" (frequency 155, centrality 0.15), "storage and preservation" (frequency 120, centrality 0.12), "antioxidant activity" (frequency 110, centrality 0.10), "fruit quality" (frequency 90, centrality 0.08), "postharvest" (frequency 85, centrality 0.07), "processing technology" (frequency 70, centrality 0.09), and "different varieties" (frequency 65, centrality 0.06) (see Figure 2). The high co-occurrence frequency of "anthocyanins" and "antioxidant activity" highlights the importance of research into the functional components of blueberries [14].

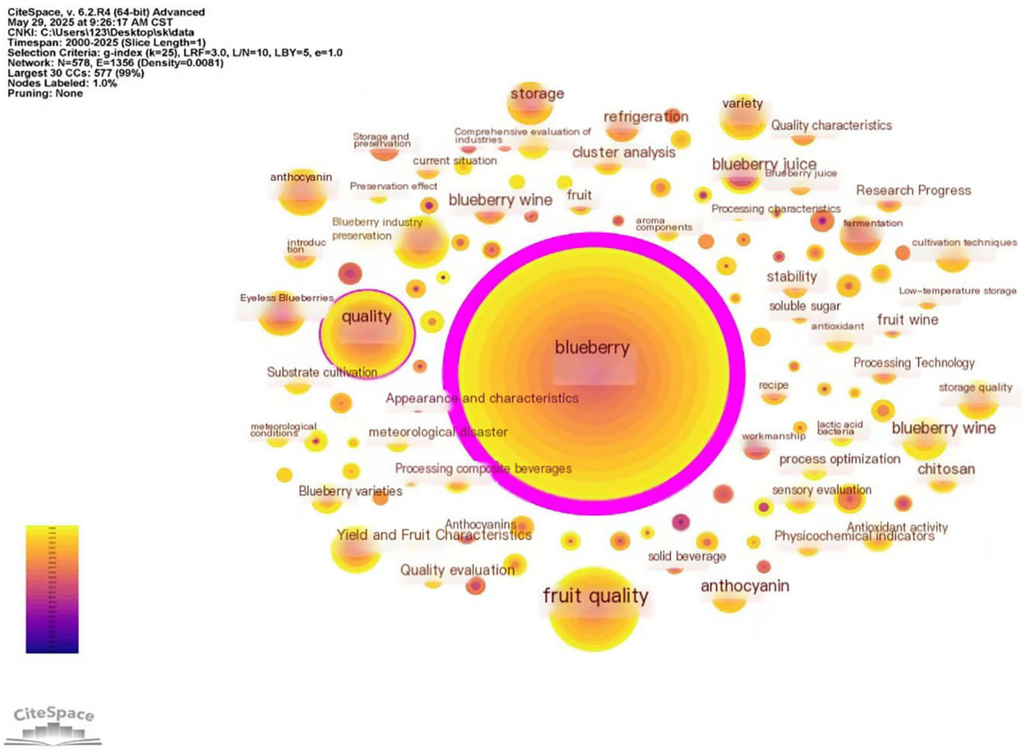

Fig. 2. "Blueberry" and "Quality" keyword co-occurrence map

3.3 Research cluster analysis

To further explore the internal structure of blueberry quality research, a cluster analysis was performed on the keyword co-occurrence network (see Figure 3). The analysis revealed eight main clusters, with a network modularity value (Q) of 0.785 and an average silhouette value (S) of 0.892, indicating a significant and highly reliable clustering structure [15]. These research topics can be condensed into four core research areas based on the keywords and content of each cluster:

- Cluster #0: Quality Analysis and Evaluation: This cluster, with keywords such as "fruit quality," "physicochemical indicators," "soluble solids," "vitamin C," "hardness," and "sensory evaluation," forms the foundation of blueberry quality research. It focuses on the systematic measurement and comprehensive evaluation of the internal and external quality indicators of blueberry fruit, such as the systematic analysis of sugar, acid, hardness, and anthocyanin content in blueberries at different maturity stages [16].

- Cluster #1: Postharvest Storage and Preservation Technology: This cluster revolves around "storage and preservation," "postharvest treatment," "shelf life," "controlled atmosphere storage," "edible coating," and "cold storage." The focus is on finding effective ways to extend the shelf life of fresh blueberries and maintain their commercial value. Notable examples of advanced research in this area include studies on combined plasma activated water and pulsed electric field treatments [17], as well as the application of 1-MCP and chitosan coatings [18].
- Cluster #2: Processing Technology and Product Development: This area involves keywords like "processing technology," "blueberry wine," "blueberry juice," "fermentation," "drying," and "extraction technology." It focuses on technological innovation for deep processing and the development of high-value-added products. This includes the optimization of blueberry wine brewing processes [19], efficient extraction techniques for anthocyanins [20], and research on the aroma quality of blueberry brandy.
- Cluster #3: Variety Resources and Cultivation Physiology: The research in this cluster includes "different varieties," "cultivation techniques," "fertilization," "growth and development," "yield," and "light." It aims to investigate the quality differences between various blueberry varieties, select high-quality and high-yield cultivation management techniques, and understand the key influence of environmental factors on blueberry quality formation. Studies such as one on the trends of quality indicators during fruit development in different blueberry varieties [21] and another on using plant hormone treatments to improve blueberry quality [22] are representative of this research direction.

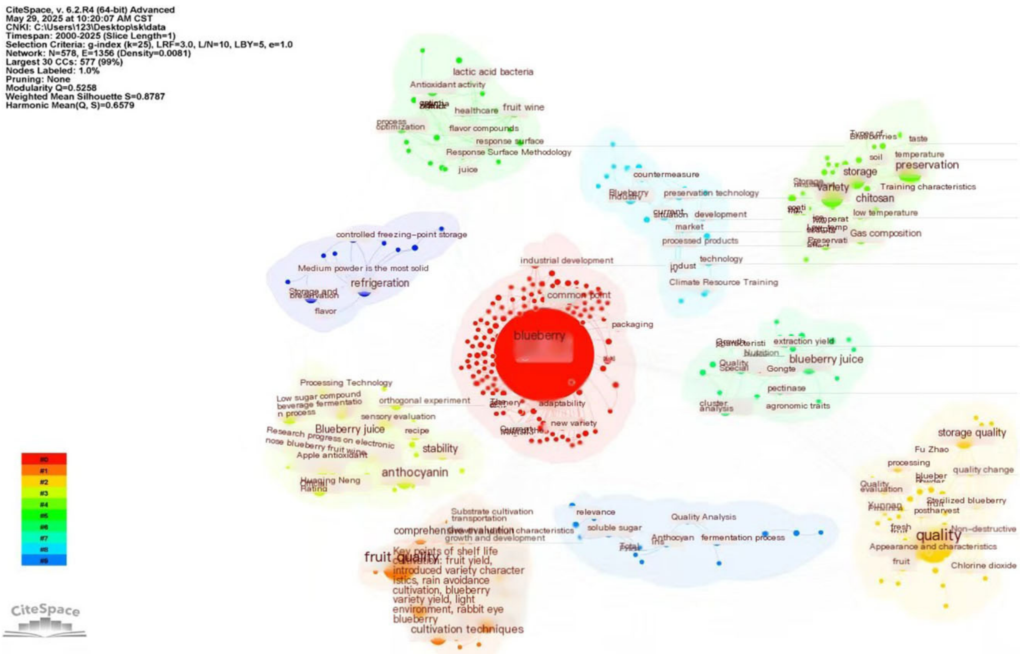

Fig. 3. "Blueberry" and "Quality" keyword cluster diagram

3.4 Institutional and author collaboration networks

Analysis of the publication institutions shows that the most prolific institutions are predominantly agricultural universities and research institutes, particularly concentrated in China's main blueberry production regions like the Northeast and East China (see Figure 4). These include Jilin Agricultural University, Liaoning Provincial Institute of Pomology, Shenyang Agricultural University, China Agricultural University, and Zhejiang University [23]. Analysis of the publication institutions shows that the most prolific institutions are predominantly agricultural universities and research institutes, particularly concentrated in China's main blueberry production regions, such as the Northeast and East China. Key institutions include Jilin Agricultural University, Liaoning Provincial Institute of Pomology, Shenyang Agricultural University, China Agricultural University, and Zhejiang University. The institutional collaboration network map reveals the formation of several regional clusters centered on core institutions, but the overall network density is low [24]. Jilin Agricultural University has demonstrated strong research capabilities in blueberry breeding, cultivation, and quality.

The author collaboration network analysis reveals that a group of core authors and research teams (see Figure 5), such as Wenlong Li (Jilin Agricultural University), Haibo Wang (Shenyang Agricultural University), and Wenlong Wu (Zhejiang University), have emerged in the field. The author collaboration network analysis reveals that a group of core authors and research teams, such as Wenlong Li (Jilin Agricultural University), Haibo Wang (Shenyang Agricultural University), and Wenlong Wu (Zhejiang University), have emerged in the field. The collaboration network presents a "core-periphery" structure, where some scholars have formed close-knit collaboration groups, but the overall network is still dominated by small-scale cooperation with limited direct links among highly productive authors [25]. This suggests the need to encourage and support the formation of large-scale, interdisciplinary, and cross-institutional research teams to tackle major scientific and industrial challenges collaboratively.

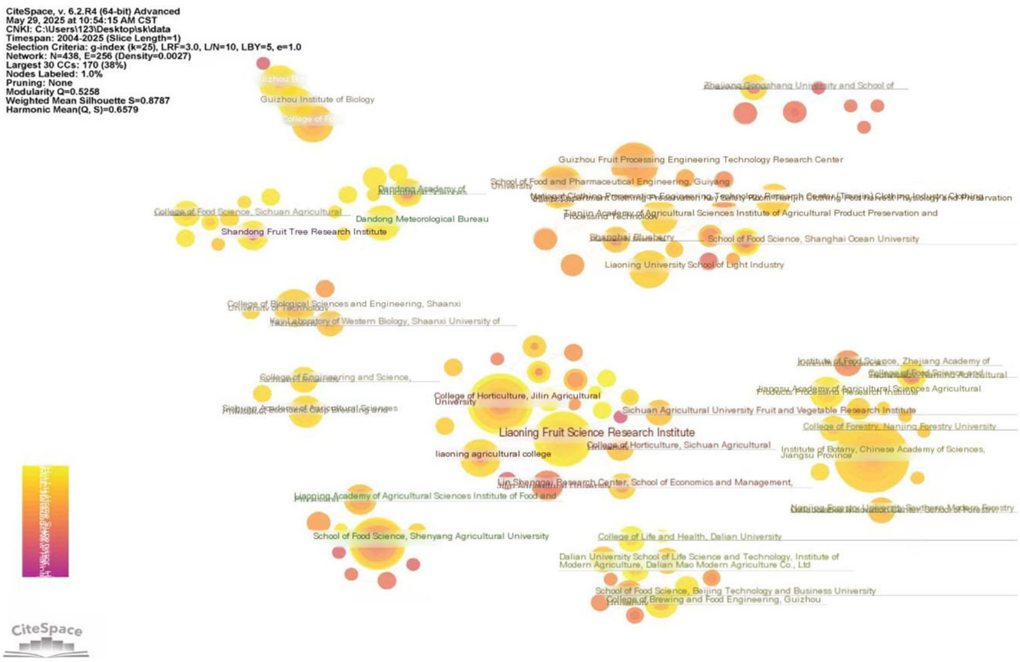

Fig. 4. Research and collaboration map of Blueberry Scientific Institutions

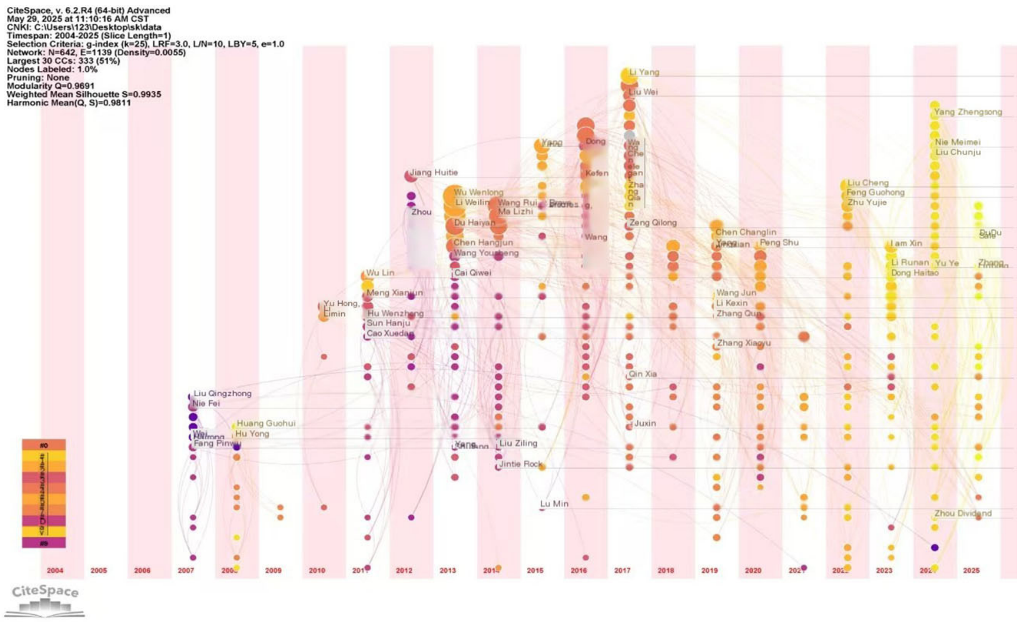

Fig. 5. Research and collaboration map of Blueberry Scientific Institutions

4 DISCUSSION

4.1 Research development stages and characteristics

This bibliometric analysis provides a systematic overview of the development of blueberry quality research in China since 2004 [26]. The "S"-shaped growth curve of publications is a typical pattern for academic disciplines, moving from an initial phase to rapid growth and finally to a stable, mature stage [27]. This trajectory is closely tied to the rapid development of the Chinese blueberry industry, increased national investment in agricultural science and technology, and the consumer-driven demand for high-quality agricultural products [28]. The research focus has evolved from a macro-level evaluation of overall quality and variety selection to a more in-depth, micro-level analysis of specific functional components (e.g., anthocyanins), optimization of postharvest preservation technologies, development of refined processed products, and even the molecular mechanisms underlying quality formation [29].

4.2 Evolution of research hotspots

The analysis of keywords and clusters provides a clear picture of how research hotspots in blueberry quality have evolved over time. Early research predominantly focused on comparing and evaluating the basic physicochemical quality of different blueberry varieties, providing foundational data for the nascent stage of the industry. As consumers became more aware of the health benefits of blueberries, functional components such as anthocyanins and their antioxidant activity became a central focus of research [29]. This shift spurred research into postharvest preservation technologies to maximize the retention of these beneficial compounds [30].

In recent years, with the expansion of the industry chain, research hotspots have shifted toward the development of high-value-added processed products, such as blueberry brandy, and a more meticulous pursuit of sensory quality, including flavor and aroma [31]. Concurrently, the introduction of advanced technologies like molecular biology, omics (e.g., transcriptomics and metabolomics), and intelligent sensing technologies (e.g., hyperspectral imaging and electronic noses) has propelled research toward deciphering the molecular mechanisms of quality formation and developing nondestructive, rapid, and intelligent quality evaluation methods. For example, studies using plant hormones to regulate quality represent an attempt at precision control [32].

4.3 Existing problems and future directions

Despite significant progress in blueberry quality research in China, several issues remain, as identified by the bibliometric analysis and current field observations.

Fragmented Research Efforts and Lack of Collaboration: Although a number of core research institutions and teams have been established, the network density of collaboration among institutions and teams remains low. The lack of large-scale, coordinated projects at the national level hinders the formation of integrated advantages necessary to solve major scientific and industrial bottlenecks [33].

Incomplete and Non-Standardized Quality Evaluation Systems: Current evaluations of blueberry quality often focus on a single or a few physicochemical indicators. A comprehensive, standardized evaluation system that considers multiple dimensions, including appearance, flavor, nutrition, safety, and processing adaptability, is lacking. This not only complicates the horizontal comparison of research findings but also restricts their effective application in the industry [34].

Disconnect between Fundamental Research and Industrial Application: A number of research findings remain at the laboratory stage and are disconnected from the actual needs of the industry, leading to a low rate of research translation. For instance, many novel preservation technologies and deep processing techniques often face practical challenges in terms of cost control, equipment compatibility, and process stability during large-scale promotion and application [35].

Insufficient In-depth Mechanistic Research: The systematic and in-depth study of the molecular regulatory networks for key quality traits (e.g., anthocyanin biosynthesis, sugar and acid metabolism, and the formation and regulation of characteristic aroma compounds) and the complex mechanisms of quality trait interaction with environmental factors is still weak. This limitation hinders the formulation of efficient molecular breeding strategies and the further development of precision cultivation techniques [36].

To address these challenges, future research should focus on the following key directions:

Strengthen interdisciplinary integration and collaboration: Future research efforts should aim to overcome the fragmentation of research by encouraging collaboration between different research institutions and industries. Large-scale, interdisciplinary research platforms should be created to foster deeper cooperation across different academic fields and regional institutions. This could promote the pooling of resources and knowledge, creating more robust and cohesive research teams. Collaborative initiatives could be supported by government funding and partnerships between academia and industry, thereby enhancing the efficiency and reach of blueberry quality research.

Develop a standardized, comprehensive blueberry quality evaluation system: The lack of a standardized quality evaluation system should be addressed by future research. A comprehensive system should be developed to assess all aspects of blueberry quality, including external attributes (size, color, and firmness), flavor (sugar-acid ratio and aroma), nutritional components (vitamins and anthocyanins), and suitability for storage and processing. Standardized methodologies should be established to enable comparison of results across different studies and ensure consistency in evaluating blueberries' quality. Research should also focus on developing nondestructive methods for quality assessment, which could facilitate real-time monitoring and improve operational efficiency.

Promote the industrialization of research outcomes: A major direction for future research is to bridge the gap between research findings and their industrial application. The current weak transformation of research outcomes into industrial applications is due to several challenges:

1. Technological difficulty: Many research findings, especially in the fields of postharvest storage, preservation, and functional component extraction, face significant technological challenges when scaled up to industrial levels. Future research should focus on overcoming these challenges by developing cost-effective, scalable technologies that are compatible with industrial equipment.
2. High costs: Many novel preservation methods and processing technologies are not cost-effective for large-scale industrial applications. Future research should focus on reducing the costs of these technologies through innovations in material selection, process optimization, and energy efficiency.
3. Poor compatibility with industrial equipment: Existing research often does not align well with industrial standards or equipment. Future studies should work on developing technologies that can be easily integrated into existing production lines or lead to the development of new, industry-compatible equipment.
4. Solutions: To overcome these obstacles, researchers should focus on the development of low-cost, scalable solutions and establish industrialization standards that can help guide the application of research outcomes in the industry. Collaboration between researchers and industry stakeholders (e.g., blueberry producers, processors, and equipment manufacturers) will be key to facilitating the translation of research findings into practical applications. Additionally, policymakers can support this process by offering incentives for industrial-academia collaborations and funding for pilot projects.

Address disconnect between fundamental research and practical needs: The gap between basic research and industry needs should be bridged by ensuring that future research is aligned with the practical challenges faced by the blueberry industry. Research should focus on developing precise methods for controlling the quality of blueberries at every stage of the supply chain, from cultivation to processing. Future studies should also emphasize the application of new technologies (e.g., omics technologies, machine learning, and artificial intelligence) to understand and regulate the molecular mechanisms behind blueberry quality formation. This would help facilitate the development of precise cultivation practices, as well as postharvest storage and preservation techniques that align with industry requirements.

5 CONCLUSION

This study provides a comprehensive overview of blueberry quality research in China based on a CiteSpace analysis of 500 articles from the CNKI database

(2004–2025). The analysis reveals that the number of publications has followed an "S"-shaped growth curve and has now reached a stable phase, contributing to the establishment of a mature knowledge system that spans quality analysis, storage and preservation, processing technology, and variety cultivation. The research hotspots have shifted from basic quality evaluation to the study of functional components, deep processing, and intelligent control. Leading institutions, such as Jilin Agricultural University, play a central role, although the collaboration network remains underdeveloped.

6 OUTLOOK AND CHALLENGES

Looking forward, research efforts should focus on the mechanisms of functional components, strengthen interdisciplinary collaboration, integrate advanced technologies, address industrial bottlenecks, establish standardized evaluation systems, and promote closer industry-academia partnerships. These actions will drive technological innovation and the sustainable development of China's blueberry industry while also meeting the growing health demands of the population.

While this study offers a macro-level insight into the field's development, the limitation of using a single data source, specifically the CNKI database, should be acknowledged. The CNKI database primarily focuses on Chinese-language publications, which may limit the inclusion of international research, particularly studies from non-Chinese-speaking countries. This could potentially result in a bias toward domestic research trends and might underrepresent global advancements in blueberry quality research.

Additionally, the CNKI database does not comprehensively capture all global research outputs, such as those from other prominent international research databases such as Scopus, Web of Science, or Google Scholar. As a result, this study's conclusions may be more reflective of research trends in China rather than a comprehensive view of global blueberry quality research. Future research would benefit from incorporating international literature to provide a broader, more balanced perspective and to assess the generalizability of the findings across different regions and research contexts.

7 FUNDING

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