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GLOBAL RESEARCH TRENDS AND EMERGING THEMES IN AMMONIUM NITRATE THERMAL STABILITY: A BIBLIOMETRIC REVIEW

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Abstract. Ammonium nitrate is a strategically important compound used in agriculture, mining, civil engineering, and energetic materials. Despite its wide application, concerns over thermal decomposition, storage stability, and explosion hazards continue to drive scientific research. This study presents a bibliometric review of global research on ammonium nitrate thermal stability based on 247 Scopus-indexed publications analyzed using Bibliometrix, Biblioshiny, and VOSviewer. Results revealed significant growth in scientific output after 2010, with China as the leading contributor. Thermal decomposition, thermodynamic stability, and decomposition kinetics were identified as dominant themes, with a clear shift from fundamental studies toward applied investigations in polymer modification, composite materials, and advanced safety strategies.

Keywords: ammonium nitrate; thermal stability; bibliometric analysis; VOSviewer; Bibliometrix; thermal decomposition; thermodynamic stability; decomposition kinetics; science mapping; knowledge structure; research trends; polymer modification; mineral additives; bentonite; glauconite.

Annotatsiya. Ammoniy nitrat qishloq xo‘jaligi, tog‘-kon sanoati, qurilish va energetik materiallarda keng qo‘llaniladigan strategik muhim birikmadir. Keng qo‘llanilishiga qaramay, termik parchalanish, saqlash barqarorligi va portlash xavfi

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bilan bog‘liq muammolar ilmiy tadqiqotlarni rag‘batlantirmoqda. Ushbu tadqiqotda Scopus bazasidan olingan 247 ta nashr asosida Bibliometrix, Biblioshiny va VOSviewer yordamida bibliometrik tahlil o‘tkazildi. Natijalar 2010-yildan keyin ilmiy ishlar sonining sezilarli o‘sganini ko‘rsatdi, Xitoy esa yetakchi hissa qo‘shuvchi sifatida ajralib chiqdi. Termik parchalanish, termodinamik barqarorlik va parchalanish kinetikasi asosiy mavzular sifatida aniqlandi; tadqiqotlar fundamental yo‘nalishdan polimer modifikatsiyasi va xavfsizlik strategiyalarini o‘z ichiga olgan amaliy yo‘nalishga bosqichma-bosqich o‘tayotgani kuzatildi.

Kalit so‘zlar: ammiakli selitra, termik barqarorlik, bibliometrik tahlil, VOSviewer, Bibliometrix, termik parchalanish, termodinamik barqarorlik; parchalanish kinetikasi, fan xaritasini tuzish, bilimlar tuzilmasi, tadqiqot tendensiyalari, polimer modifikatsiyasi, mineral qo‘shimchalar, bentonite, glaukonit.

Аннотация. Нитрат аммония является стратегически важным соединением, широко применяемым в сельском хозяйстве, горнодобывающей промышленности, строительстве и энергетических материалах. Несмотря на широкое использование, проблемы термического разложения, стабильности при хранении и взрывоопасности продолжают стимулировать научные исследования. В данной работе представлен библиометрический обзор мировых исследований термической устойчивости нитрата аммония на основе 247 публикаций из базы данных Scopus, проанализированных с помощью Bibliometrix, Biblioshiny и VOSviewer. Результаты выявили значительный рост научной продукции после 2010 года, при этом Китай занял лидирующую позицию. Термическое разложение, термодинамическая устойчивость и кинетика разложения определены как доминирующие темы; отмечен постепенный переход от фундаментальных исследований к прикладным, включающим модификацию полимеров, композитные материалы и передовые стратегии безопасности.

Ключевые слова: селитра аммония; термостойкость; библиометрический анализ; VOSviewer; Библиометрия; термическое разложение; термодинамическая устойчивость; кинетика разложения; научное картирование; структура знаний; тенденции исследований; модификация полимеров; минеральные добавки; бентонит; глауконит.

INTRODUCTION.

Ammonium nitrate (AN) is one of the most important nitrogen-containing compounds used worldwide due to its extensive applications in agriculture, mining, civil engineering, and defense-related industries. Owing to its high nitrogen content, relatively low production cost, and excellent agronomic efficiency,

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ammonium nitrate has remained a key component of nitrogen fertilizers for several decades. The global demand for food production and sustainable agricultural practices continues to drive the widespread utilization of ammonium nitrate-based fertilizers, particularly in regions with intensive crop cultivation. Beyond its agricultural significance, ammonium nitrate is also an essential constituent of energetic materials. Its strong oxidizing properties make it suitable for use in industrial explosives, propellants, and blasting agents employed in mining and construction activities. Ammonium nitrate fuel oil (ANFO), for example, remains one of the most widely used industrial explosives due to its cost-effectiveness and operational performance. As a result, ammonium nitrate occupies a unique position as a material of strategic importance, serving both agricultural and industrial sectors.

The broad range of applications associated with ammonium nitrate has stimulated extensive scientific research aimed at improving its performance, safety, storage characteristics, and environmental compatibility. Advances in thermal analysis, materials engineering, and chemical modification techniques have further expanded research efforts dedicated to understanding the physicochemical behavior of ammonium nitrate under different operating and storage conditions. Despite its widespread utilization, ammonium nitrate presents several challenges related to thermal stability and safety. The compound undergoes a series of phase transitions and thermal decomposition reactions that can significantly affect its physical properties and operational reliability. Under elevated temperatures, ammonium nitrate may decompose through complex reaction pathways involving the formation of gaseous products such as nitrogen oxides, ammonia, and water vapor. The decomposition process is influenced by numerous factors, including temperature, pressure, impurities, moisture content, particle morphology, and the presence of catalytic substances.

Thermal instability represents one of the most critical concerns associated with ammonium nitrate. Inadequate storage conditions, contamination with combustible materials, confinement, or prolonged exposure to heat may accelerate decomposition reactions and increase the likelihood of thermal runaway events. Several major industrial accidents occurring over the past decades have demonstrated the potentially catastrophic consequences of uncontrolled ammonium nitrate decomposition. These incidents have intensified scientific and regulatory interest in improving the safety profile of ammonium nitrate during production, transportation, and storage.

In addition to explosion hazards, storage-related problems such as moisture absorption, caking, phase transformations, and degradation of granule integrity

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may adversely affect product quality and handling characteristics. Consequently, enhancing the thermal stability and storage safety of ammonium nitrate remains a priority research area for both academic institutions and industrial stakeholders. Recent investigations have focused on the development of stabilizing additives, surface coatings, polymeric modifiers, and mineral-based materials capable of improving thermal resistance while maintaining fertilizer performance and economic feasibility.

The growing volume of scientific publications related to ammonium nitrate thermal stability has created a need for systematic approaches capable of evaluating research development, identifying influential contributors, and revealing emerging scientific trends. Traditional literature reviews provide valuable qualitative insights; however, they often face limitations in handling large datasets and objectively assessing the evolution of a research field over extended periods. Bibliometric analysis has emerged as an effective quantitative methodology for mapping scientific knowledge and evaluating research performance. By applying statistical and network-based techniques to bibliographic data, bibliometric studies can identify publication patterns, collaboration networks, influential authors, leading institutions, highly cited publications, and thematic structures within a particular field. Furthermore, advanced visualization tools such as VOSviewer and Bibliometrix enable the exploration of conceptual relationships among keywords, research clusters, and thematic evolution over time.

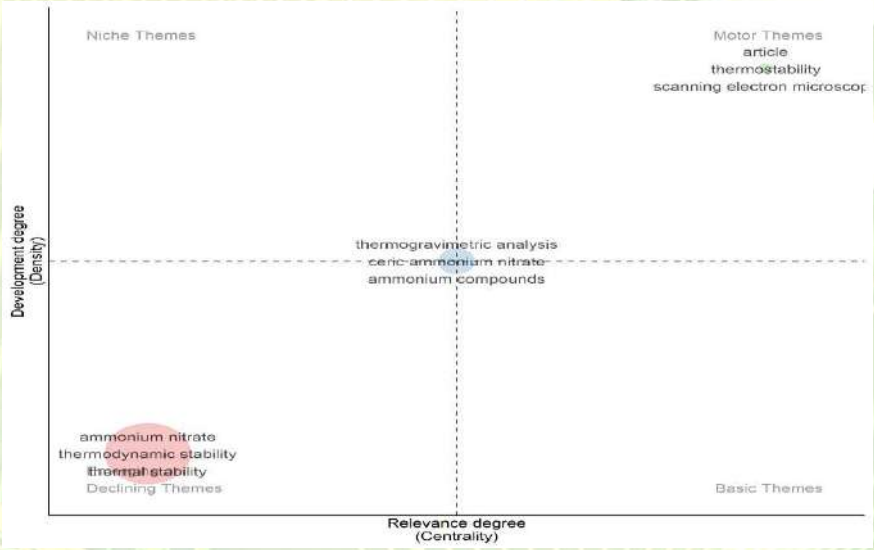


Fig. 1. Thematic Map of Research on Ammonium Nitrate Thermal Stability

Fig. 1 presents a thematic map generated from keyword co-occurrence analysis. The map classifies research themes according to their centrality and development density. "Thermostability", "silica", and "scanning electron microscopy" appear as motor themes, indicating their strong relevance and high level of development within the field. In contrast, "ammonium nitrate", "thermal

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stability", and related terms are positioned among emerging or declining themes, suggesting evolving research directions and opportunities for further investigation.

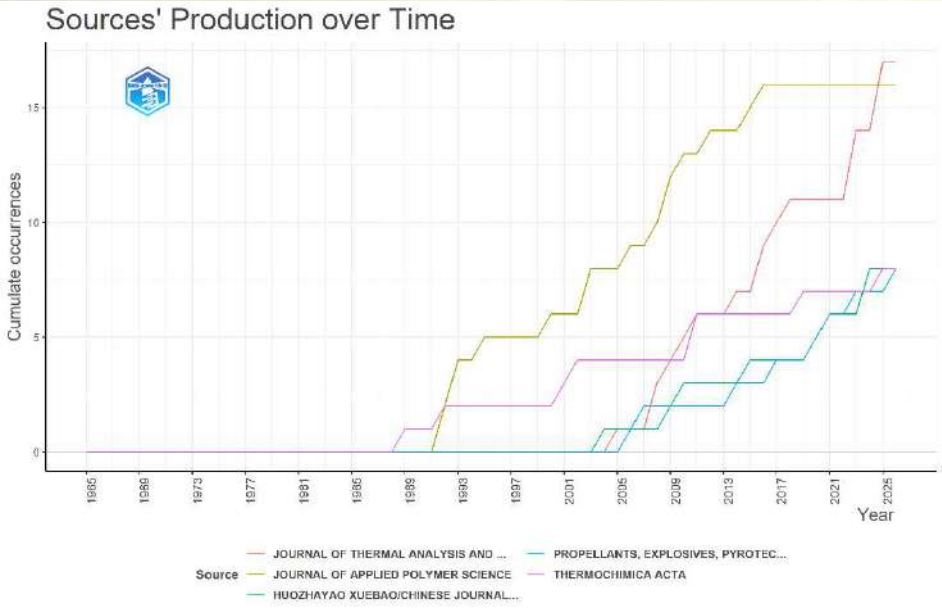


Fig. 2. Sources' Production Over Time in Ammonium Nitrate Thermal Stability Research

Fig. 2 depicts the cumulative scientific production of the most productive journals in the field. The results indicate a continuous increase in publications over time, with journals specializing in thermal analysis, polymer science, energetic materials, and thermochemistry contributing significantly to the development of ammonium nitrate thermal stability research.

In the context of ammonium nitrate thermal stability research, bibliometric analysis offers a comprehensive framework for understanding how scientific interest has evolved, which topics have received the greatest attention, and which emerging areas may shape future investigations. Such information is valuable for researchers, industry practitioners, and policymakers seeking to identify knowledge gaps and establish future research priorities.

The present study aims to provide a comprehensive bibliometric assessment of global research on ammonium nitrate thermal stability. Specifically, the study seeks to evaluate publication growth, identify the most productive authors, institutions, countries, and journals, and determine the intellectual and conceptual structure of the field through citation and keyword analyses. In addition, the study explores thematic evolution, research hotspots, collaboration patterns, and emerging scientific directions associated with ammonium nitrate thermal stability. By combining bibliometric indicators with science mapping techniques, this work provides a systematic overview of the current state of knowledge and highlights future opportunities for research related to thermal stabilization, decomposition

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control, safety enhancement, and advanced modification strategies for ammonium nitrate-based materials.

MATERIALS AND METHODS.

The bibliographic data analyzed in this study were retrieved from the Scopus database, one of the largest and most comprehensive abstract and citation indexing platforms for peer-reviewed scientific literature. Scopus was selected as the primary data source due to its extensive coverage of high-quality journals, conference proceedings, review articles, and interdisciplinary research outputs. Compared with other bibliographic databases, Scopus provides a broad representation of scientific publications and includes detailed citation information, making it particularly suitable for bibliometric investigations.

To ensure consistency and reliability, all records were collected from a single database. The search strategy was designed to capture publications specifically related to the thermal stability of ammonium nitrate. The search query was conducted using the keywords “ammonium nitrate” and “thermal stability” within article titles, abstracts, and author keywords. The following search expression was applied: TITLE-ABS-KEY ("ammonium nitrate") AND TITLE-ABS-KEY ("thermal stability") The search was performed on a single date to avoid variations caused by continuous database updates. All available records matching the search criteria were exported in CSV format, including bibliographic information such as titles, authors, affiliations, publication years, abstracts, keywords, source titles, references, and citation data. A total of 247 documents were identified and included in the analysis. The retrieved dataset represents the global scientific literature associated with ammonium nitrate thermal stability and encompasses contributions from various disciplines, including chemical engineering, materials science, thermochemistry, energetic materials, polymer science, environmental science, and industrial safety. The collected records formed the basis for subsequent bibliometric and scientometric analyses aimed at evaluating publication trends, scientific impact, collaboration networks, thematic structures, and emerging research directions within the field.

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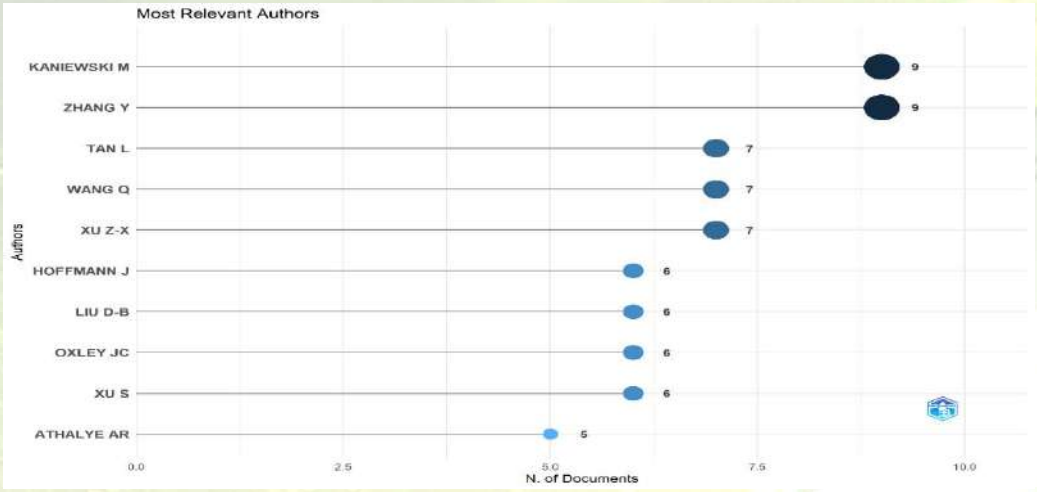


Fig. 3. Most Relevant Authors in Ammonium Nitrate Thermal Stability Studies

Fig. 3 presents the most productive authors based on the number of publications. The analysis highlights the leading contributors who have played a significant role in advancing knowledge related to thermal decomposition, stability enhancement, and safety assessment of ammonium nitrate-based systems.



Fig. 4. Most Locally Cited Documents in the Research Field

Fig. 4 depicts the most locally cited publications within the analyzed dataset. These highly cited studies represent the intellectual foundation of research on ammonium nitrate thermal stability and provide key insights into decomposition mechanisms, material modification, and thermal characterization techniques.

Evolution of Research Topics

The temporal evolution of research topics provides valuable insights into the development of scientific interests and emerging directions within the field of ammonium nitrate thermal stability. Analysis of trend topics revealed a progressive shift in research focus over the study period, reflecting both advances in analytical techniques and growing concerns regarding the safety and performance of ammonium nitrate-based materials.

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During the early stages of research, scientific investigations were primarily concentrated on the fundamental thermal behavior of ammonium nitrate. Topics such as thermal decomposition, decomposition kinetics, activation energy, phase transitions, thermodynamic stability, and calorimetric characterization dominated the literature. Researchers sought to establish a comprehensive understanding of the mechanisms governing thermal degradation and the factors influencing the stability of ammonium nitrate under various operating conditions. Experimental techniques including differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and differential thermal analysis (DTA) were extensively employed to characterize decomposition pathways and evaluate thermal performance.

As the field matured, attention gradually expanded toward issues associated with industrial safety, storage stability, and hazard prevention. Studies increasingly addressed topics related to thermal runaway processes, explosive behavior, self-sustaining decomposition reactions, and the influence of impurities on thermal stability. This transition was largely driven by growing awareness of the risks associated with the large-scale production, transportation, and storage of ammonium nitrate.

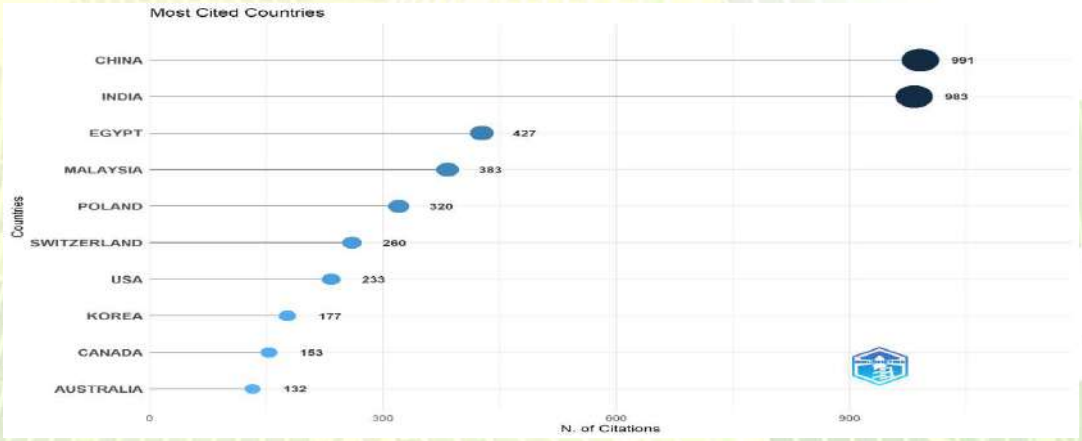


Fig. 5. Most Cited Countries in Ammonium Nitrate Thermal Stability Research

Fig. 5 presents the distribution of citations by country. China and India demonstrate the highest citation impact, reflecting their substantial contribution to scientific research in thermal stability, decomposition kinetics, and safety enhancement of ammonium nitrate materials.

In recent years, a noticeable shift toward advanced material engineering approaches has been observed. Emerging research themes include polymer modification, graft copolymerization, composite materials, surface treatment technologies, and functional additives designed to improve thermal stability and overall safety performance. The increasing appearance of terms associated with

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material modification indicates a movement from purely descriptive studies toward the development of practical stabilization strategies capable of enhancing the physicochemical properties of ammonium nitrate.

The trend analysis also highlights the growing integration of modern characterization methods, including spectroscopic techniques, microscopic investigations, and advanced thermal analysis approaches. These methods have enabled a deeper understanding of structure–property relationships and have facilitated the design of more effective stabilization systems.

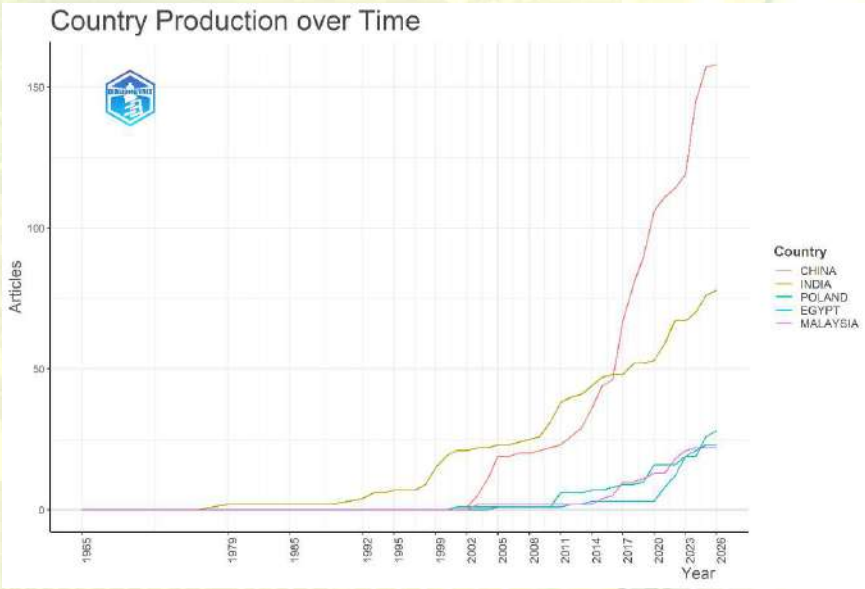


Fig. 6. Country Scientific Production Over Time

Fig. 6 depicts the evolution of scientific production across different countries. A significant increase in publication output is observed during the last decade, particularly in China, indicating growing global interest in ammonium nitrate thermal behavior, safety issues, and advanced stabilization technologies.

Future Research Directions

The bibliometric findings indicate that research on ammonium nitrate thermal stability has evolved considerably over the past decades, progressing from fundamental studies of decomposition mechanisms toward the development of advanced stabilization technologies. Despite these advancements, several important scientific and technological challenges remain unresolved, providing opportunities for future investigations.

One of the most promising research directions involves the development of effective thermal stabilization strategies capable of improving the safety and storage performance of ammonium nitrate without compromising its functional properties. Although numerous additives and modification approaches have been proposed, the mechanisms governing thermal stabilization are not yet fully understood. Future studies should therefore focus on elucidating the

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physicochemical interactions between ammonium nitrate and stabilizing agents at both molecular and microstructural levels.

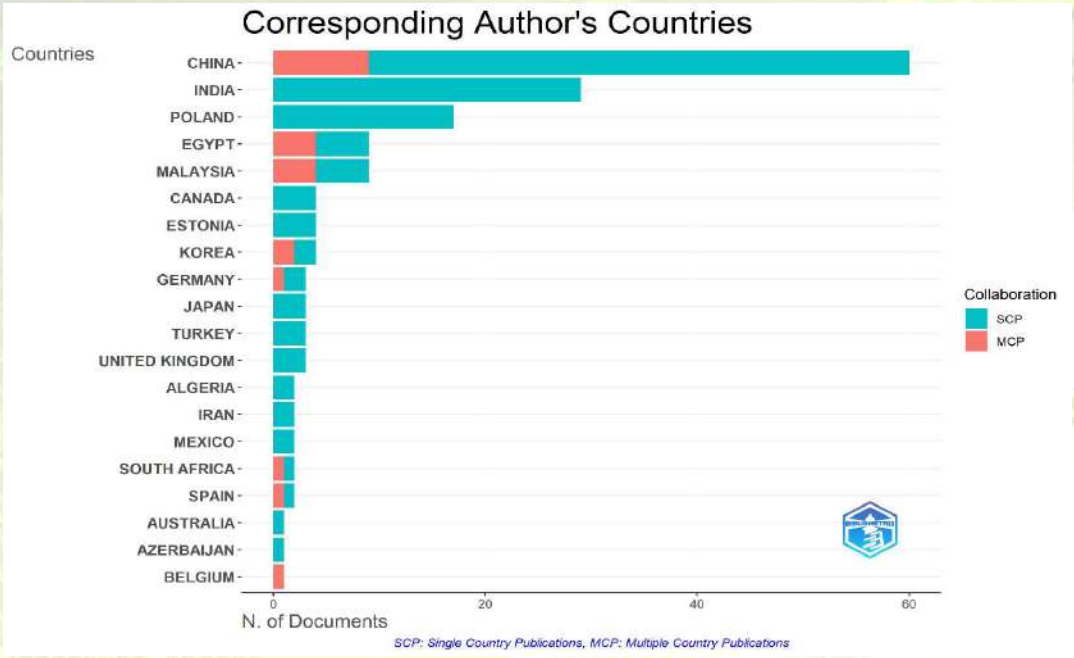


Fig. 7. Corresponding Author's Countries and International Collaboration Patterns

Fig. 7 presents the geographical distribution of corresponding authors and distinguishes between single-country publications (SCP) and multiple-country publications (MCP). The results reveal active international collaboration networks, with China, India, and Poland emerging as major contributors to global research activities.

Particular attention should be directed toward naturally occurring clay minerals, which have attracted increasing interest due to their abundance, low cost, environmental compatibility, and multifunctional properties. Clay minerals possess unique structural characteristics, including high specific surface area, ion-exchange capacity, and adsorption capability, making them attractive candidates for improving the thermal behavior and storage stability of ammonium nitrate-based materials. Among the various mineral additives, bentonite represents a particularly promising material. Owing to its layered aluminosilicate structure and high adsorption capacity, bentonite may contribute to moisture regulation, reduction of caking tendencies, and enhancement of thermal resistance. Nevertheless, the influence of bentonite on decomposition kinetics, phase transformations, and long-term storage stability remains insufficiently explored and requires systematic investigation.

Similarly, glauconite has received limited attention despite its potential advantages as a functional mineral modifier. The unique mineralogical composition of glauconite suggests that it may influence heat transfer processes,

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moisture retention behavior, and structural stability of ammonium nitrate granules. However, comprehensive studies examining its role in thermal stabilization, explosion hazard reduction, and fertilizer performance are still scarce. The absence of detailed investigations in this area highlights a significant knowledge gap and an important opportunity for future research.

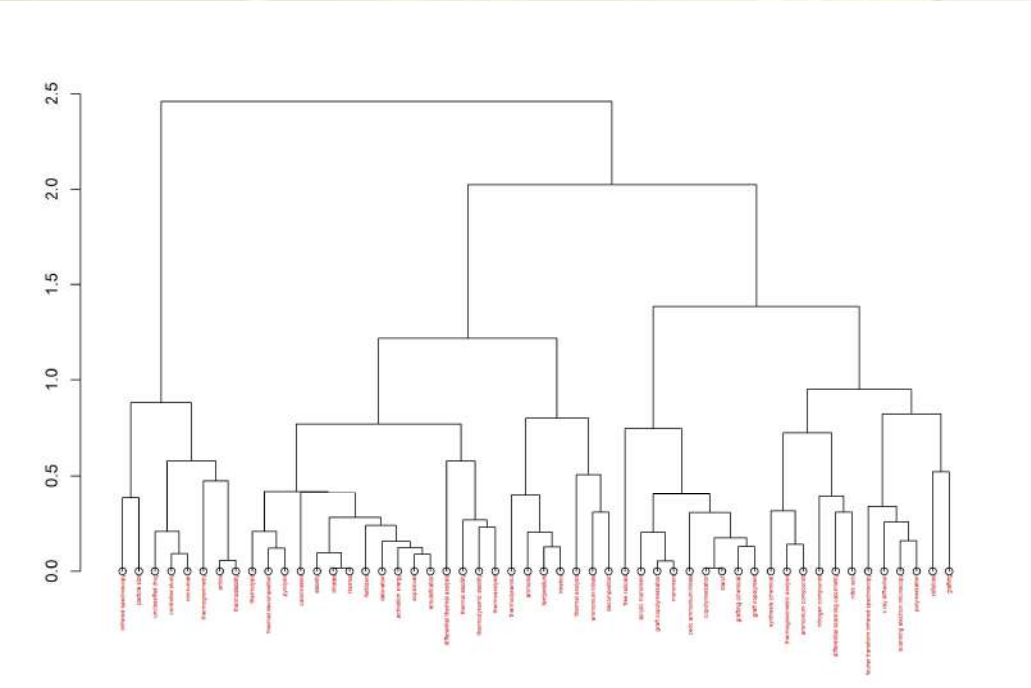


Fig. 8. Hierarchical Clustering of Research Themes

Fig. 8 depicts a hierarchical clustering dendrogram generated from keyword relationships. The clustering structure reveals several interconnected thematic groups, reflecting the multidisciplinary nature of research involving ammonium nitrate thermal stability, energetic materials, decomposition processes, and advanced material characterization techniques.

Another critical direction involves the development of advanced anti-caking materials capable of simultaneously improving mechanical strength, moisture resistance, and thermal stability. Existing anti-caking technologies often focus on a single performance parameter, whereas future solutions should adopt a multifunctional approach that addresses both storage and safety requirements. The integration of mineral modifiers with surface coating technologies may provide a viable pathway toward achieving these objectives.

Future research should also prioritize the design of safer fertilizer formulations that minimize the risks associated with thermal decomposition, accidental ignition, and long-term storage. The increasing demand for safe agricultural products and stricter industrial safety regulations will likely accelerate efforts aimed at developing next-generation ammonium nitrate fertilizers with enhanced stability characteristics.

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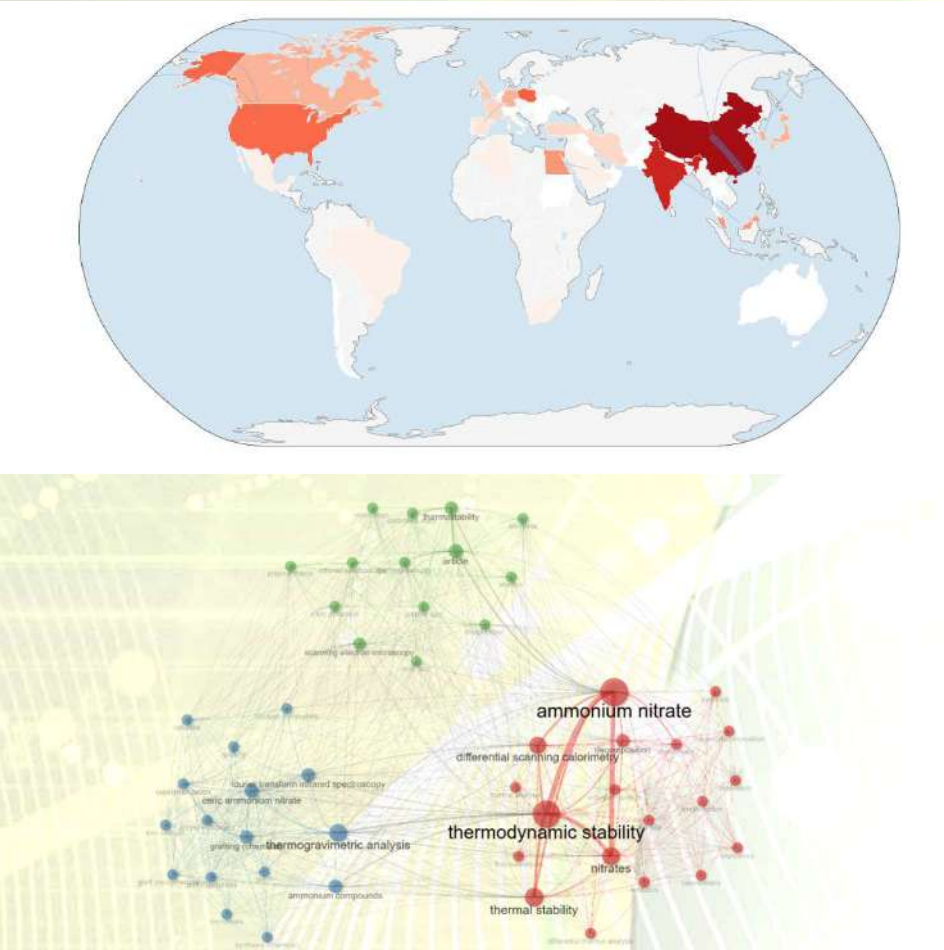


Fig. 9-10. Keyword Co-occurrence Network in Ammonium Nitrate Thermal Stability Research

Fig. 9-10 presents a keyword co-occurrence network generated using VOSviewer. The network reveals several thematic clusters centered on "ammonium nitrate" and "thermal stability". Strong connections between keywords indicate the dominant research focus on thermodynamic stability, decomposition behavior, thermal analysis, and material modification strategies.

CONCLUSIONS.

This study provided a comprehensive bibliometric assessment of the global research landscape on ammonium nitrate thermal stability based on publications indexed in the Scopus database. The results revealed a substantial expansion of scientific activity in this field, reflecting increasing academic and industrial interest in the thermal behavior, safety, and stabilization of ammonium nitrate-based materials. The analysis demonstrated a marked growth in publication output after 2010, indicating that concerns related to thermal decomposition, industrial safety, and storage stability have become increasingly important research priorities. The upward publication trend also reflects advances in thermal characterization

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techniques and the growing demand for safer and more reliable ammonium nitrate formulations.

Country-level analysis showed that China occupies a leading position in terms of both scientific productivity and citation impact. The strong contribution of Chinese research institutions, together with increasing international collaboration, has played a significant role in shaping the development of this research area. Several other countries, including India and European nations, have also contributed substantially to the advancement of knowledge related to ammonium nitrate thermal stability. Keyword and thematic analyses revealed that thermal decomposition, thermodynamic stability, decomposition kinetics, and thermal analysis remain the fundamental pillars of research in this field. These topics continue to provide the scientific basis for understanding the mechanisms governing ammonium nitrate behavior under various thermal and environmental conditions.

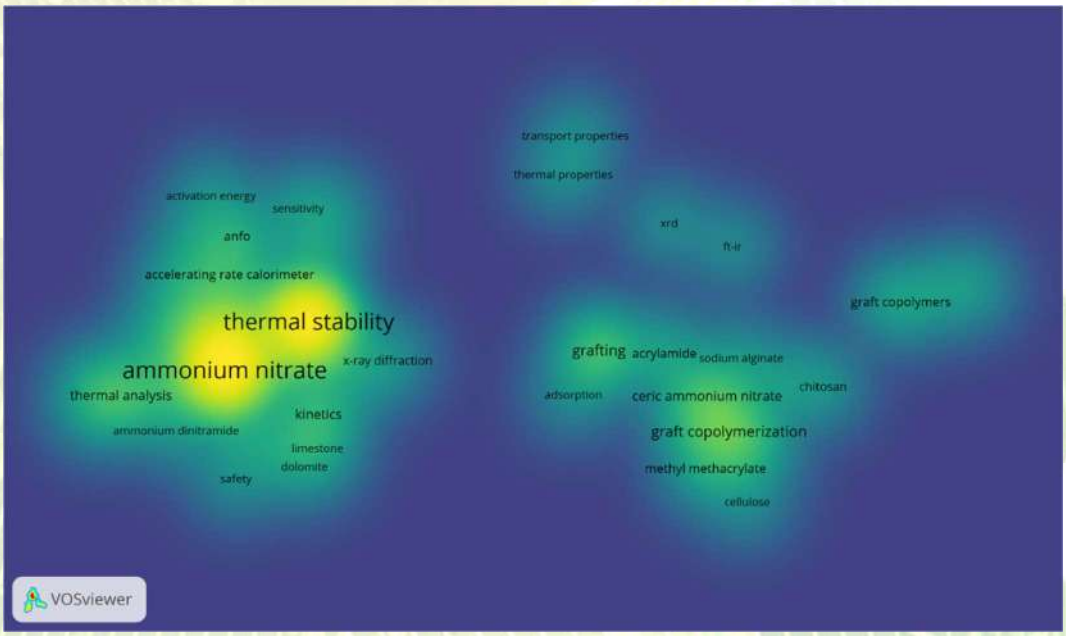


Fig. 11. Authors' Scientific Production Over Time

Fig. 11 depicts the temporal evolution of publication activity among the most productive authors. The figure demonstrates sustained research contributions over multiple years and highlights the increasing scientific attention devoted to ammonium nitrate stability and safety-related studies.

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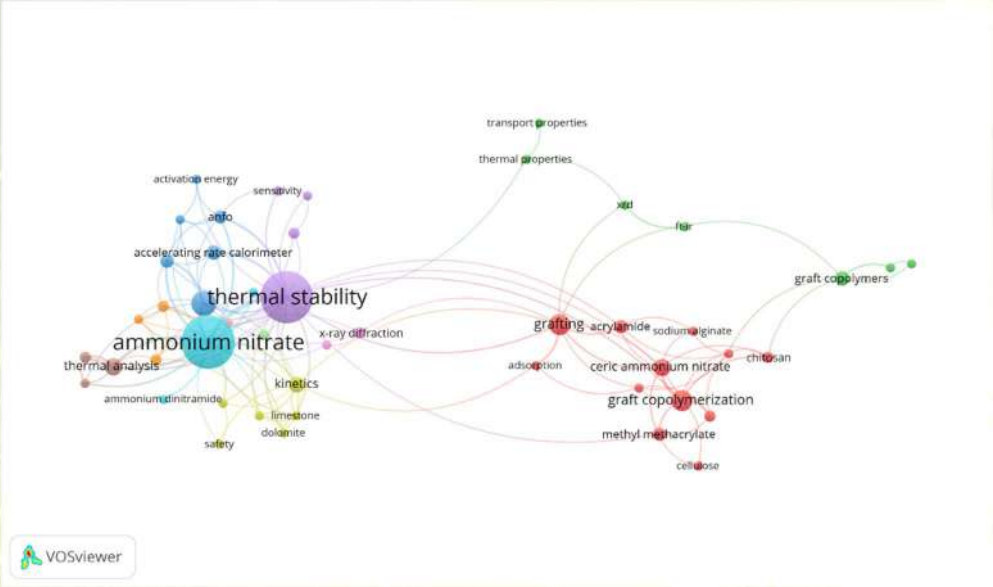


Fig. 12. Keyword Network Visualization of Research Themes

Fig. 13 presents a network visualization of keyword relationships. Distinct clusters correspond to different research directions, including thermal decomposition, energetic materials, polymer modification, thermodynamic behavior, and safety assessment. The strong interconnections among clusters demonstrate the multidisciplinary nature of ammonium nitrate thermal stability research.

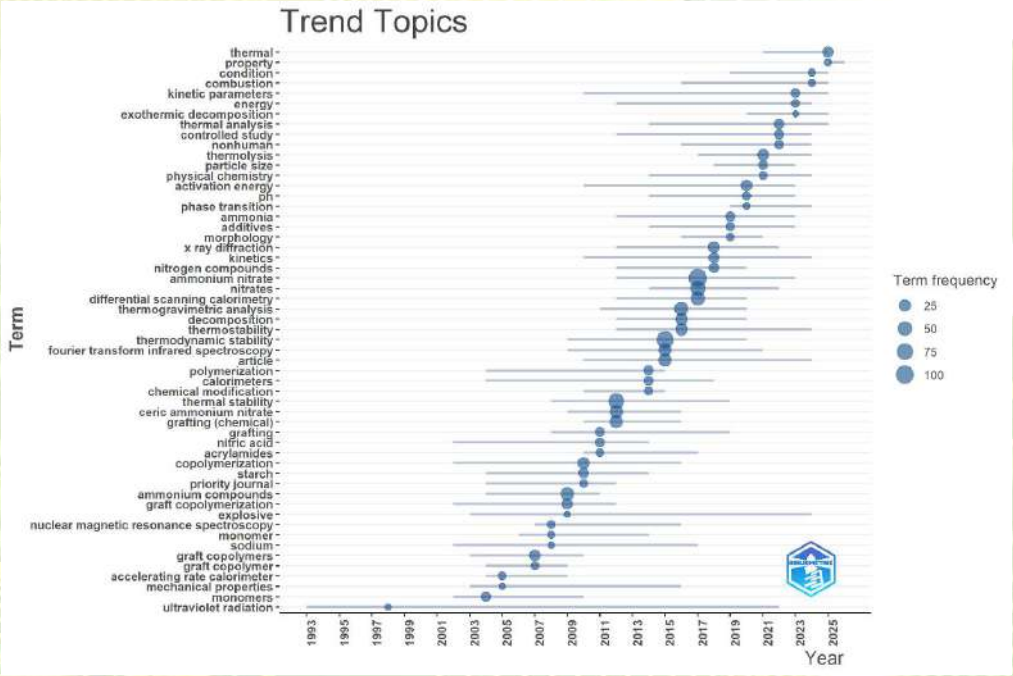


Fig. 13 Trend Topics Evolution in Ammonium Nitrate Thermal Stability Research

Fig. 13 depicts the temporal evolution of research topics across the study period. The figure shows how scientific interest has shifted from fundamental studies of decomposition and thermal analysis toward advanced themes such as

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kinetic modeling, polymer modification, thermal stabilization, and safety enhancement strategies. The evolution of research themes further demonstrated a gradual transition from fundamental thermal studies toward application-oriented approaches focused on material modification and safety enhancement. In particular, polymer-based modification strategies have emerged as an important and rapidly growing research direction aimed at improving the thermal performance and storage characteristics of ammonium nitrate. The findings also highlight significant opportunities for future investigations involving mineral-based stabilization technologies. Natural clay minerals, especially bentonite and glauconite, represent promising yet insufficiently explored materials with the potential to enhance thermal stability, reduce caking tendencies, and improve the overall safety profile of ammonium nitrate products. Consequently, the integration of sustainable mineral modifiers into ammonium nitrate formulations may constitute an important research frontier for the development of safer, more stable, and environmentally responsible fertilizer systems.

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