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Deciphering the Impact of Nanoparticles in Tobacco Research through Scientometric Analysis: A Methodological Perspective

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Abstract: *This study uses bibliometric analysis to systematically examine the status and trends of nanoparticle applications in tobacco research from 2000 to 2023. By analyzing 749 documents, it identifies research hotspots, key institutions, leading authors, collaboration networks, and high-impact journals. The results show that nanotechnology holds great potential for enhancing tobacco growth, disease prevention, gene expression regulation, and stress resistance. The study also explores potential environmental and health risks of nanoparticles, highlighting the need for scientific research to ensure safe application. Keyword co-occurrence analysis predicts future directions in tobacco research, such as virus-based biomass utilization, green synthesis of nanomaterials, and vaccine development applications. This research provides a scientific foundation for the future development of nanoparticles in tobacco research and valuable references for researchers aiming to innovate nanotechnology applications in agriculture.*

Keywords: *Nanotechnology applications, Tobacco research, Bibliometric analysis, Environmental safety, Interdisciplinary collaboration*

1. Introduction

Nanoparticles (NPs) refer to particles with sizes ranging from 1 to 100 nm [1], which often exhibit unique biological properties within this size range. Controlled, simple, economical, and safe nanomaterials are essential for the development of modern nanotechnology, and the synthesis of nanomaterials, especially nanoparticles, has been proven to be environmentally safe and economical [2]. Consequently, nanotechnology has been widely applied in the field of plant agriculture. Given the significant effects of nanoparticles, researchers have begun to pay special attention to the interactions between nanoparticles and specific plants, with tobacco, as an economically significant crop, garnering particular interest. Studies have shown that tobacco plants can absorb nanoparticles and that these particles can be translocated within the plant, exhibiting significant effects on tobacco [3-6]. These effects are influenced by various factors, including the type, shape, and concentration of nanoparticles. Thus, it is crucial to explore how these parameters affect the interaction between nanoparticles and tobacco to assess potential harms. Moreover, given tobacco's susceptibility to a wide range of pests and diseases, the application of nanotechnology in virus control, such as the treatment of tobacco mosaic disease and root-knot nematodes, demonstrates the potential of nanoparticles in agricultural applications [7-11], Despite the widespread scientific interest in the interactions between nanoparticles and tobacco, there remains a knowledge gap regarding the hotspots and development trends in this field. Filling this gap through a systematic review of studies on the interaction between nanoparticles and plants over the past two decades has become a focal point of this paper.

2. Materials and Methods

2.1. Data Sources

This study used data from the Web of Science Core Collection, a widely accepted database in scientific research. We quickly retrieved publication details about nanoparticles in tobacco, ensuring no recent updates were missed. The search included titles, abstracts, authors, institutions, and references, all saved in plain text format. The query was: (nano-related terms) AND (tobacco-related terms) AND

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(plant), from 2000 to December 3, 2023. Only English articles and reviews were considered. We found 643 articles and 106 reviews, exported in batches of 500 with full records and references. Full Record and Cited References" in plain text file format.

2.2. Data Analysis and Visualization

In this research, we used CiteSpace (vV.6.2.R4) for bibliometric data visualization. These platforms offer co-authorship, co-citation, and co-occurrence analyses. Co-authorship explores relationships between authors, countries, or institutions based on shared publications. Co-occurrence analyzes relationships between items that occur together, while co-citation shows relationship strength between cited items. CiteSpace helped us visualize co-citation networks of countries/regions, institutions, and keyword co-occurrences. CiteSpace analyzed co-authorship networks of institutions and authors, and co-citation networks of authors, references, and journals. It also created dual-map overlays of journals to identify research hotspots and interdisciplinary content. To ensure accuracy and reproducibility, we analyzed data in text format using Microsoft Excel 2019 and GraphPad Prism 8. We exported bar charts and tables for key metrics like cited authors, countries/regions, publications, journals, and institutions.

3. Results and Discussion

3.1. Analysis of Annual Publication Volume

The number of publications serves as a concrete indicator of the vitality and academic excellence in a research area, providing insights into the scientific contributions and global impact of specific countries or regions. Figure 1 depicts a clear J-shaped growth in the number of publications in this field from 2000 to 2023.

Since 2000, research on nanoparticles in tobacco has shown a consistent annual increase, averaging 57 publications per year from 2014 to 2023. This significantly surpasses the average of 16 publications per year in the previous decade (2004-2013). Notably, the past five years have seen a sharp rise, accounting for half of the total publications. This trend reflects a growing academic interest in the effects of nanoparticles on tobacco, marked by increasing engagement over time. The strong correlation between the year and publication volume (R^2=0.9123) suggests that this upward trend is likely to continue beyond 2023.

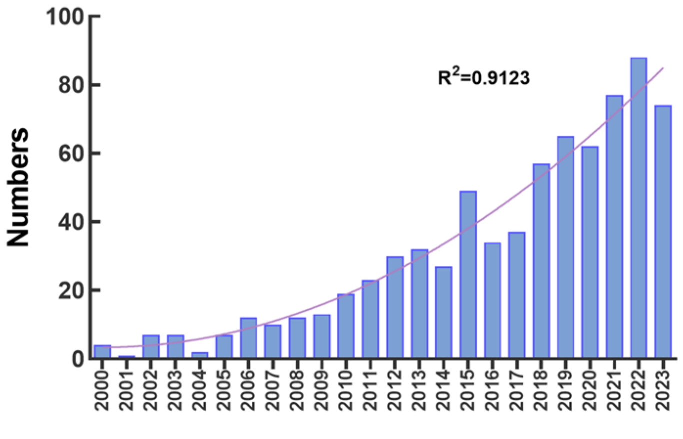

Figure 1: The annual number of studies on the effects of tobacco involving nanoparticles, from 2000 to 2023, is shown in a blue bar chart. The lines in the chart represent a linear fitting analysis of the publication data.

3.2. Analysis by Country/Region

An analysis of the global scene shows that 73 countries/regions have conducted research in this field. Figure 2A illustrates the geographical distribution and publication output, with the United States, China, and Germany each exceeding the 100-article threshold. Figure 2B outlines the annual publication trends of the top 10 countries since 2000, noting significant spikes in publications from the United States and China, in contrast to the more gradual increases seen in other nations. Figure 2C ranks the top five

ISSN 2616-5910 Vol. 6, Issue 1: 1-7, DOI: 10.25236/AJALS.2025.060101

countries based on their publication share, while Figure 2D, utilizing VOSviewer analysis with a threshold of five publications per country (covering 33 countries), visualizes the collaborative networks. In this depiction, node size reflects a country's contribution to the field, and line thickness indicates the strength of collaborations between countries, measured by Total Link Strength (TLS). Notably, the United States stands as a central node, particularly in its collaborations with China and Germany, where the strongest linkage signifies the most intense cooperative research endeavors. The United States' extensive network underscores its crucial role and dedication to international collaboration, reinforcing its leadership position in the domain.

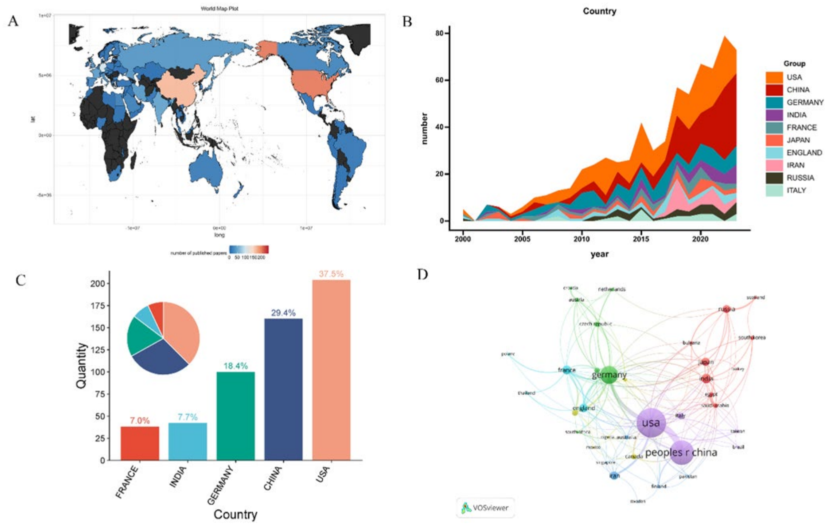

Figure 2: (A) World map based on the total publications of different countries/regions. (B) The changing trend of the annual publication quantity in the top 10 countries/regions.(C)The top five countries with the highest number of posts and the proportion of the number of posts. (D) The countries/regions' citation network visualization map generated by using VOSviewer.

3.3. Institutional Analysis

This study encompasses an analysis of 360 institutions that have engaged in examining the impact of nanoparticles on tobacco. As delineated in Table 1, the foremost contributors include Case Western Reserve University, the University of California System, and the Chinese Academy of Sciences, with respective publication outputs of 38 papers (5.073%), 38 papers (5.073%), and 27 papers (3.605%). Notably, the top ten institutions comprise three entities each from the United States, Germany, and China, underscoring their leading positions in nanotechnology research.

Table 1: Top 10 institutes in the publications concerning the research of NPs on tobacco.

Rank	Sources title	number of published papers	% Of 749	Country	Total citations
1	Case Western Reserve University	38	5.073	USA	1966
2	University of California System	38	5.073	USA	1654
3	Chinese Academy of Sciences	27	3.605	CHINA	807
4	Centre National de la Recherche Scientifique (CNRS)	26	3.471	FRANCE	627
5	University of California San Diego	25	3.338	USA	688
6	Helmholtz Association	24	3.204	GERMANY	599
7	China National Tobacco Corporation	23	3.071	CHINA	407
8	Southwest University - China	21	2.804	CHINA	588
9	University of Stuttgart	21	2.804	GERMANY	771
10	RWTH Aachen University	19	2.537	GERMANY	523

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The lag observed in other nations regarding nanotechnology advancements could be attributed to various factors, such as delayed entry into nanotechnology research, inadequate funding, a scarcity of skilled personnel in the field, and limited international collaboration and competition[12-16], These elements collectively contribute to the technological lag experienced by these nations. It is imperative for countries to augment their research and development expenditures, attract and nurture high-caliber talents, refine policy frameworks and institutional landscapes, bolster international collaborations, foster industrial innovation, and undertake groundbreaking research[17-19],Such initiatives will elevate the quality of scholarly publications and enhance the global stature of national institutions within the nanotechnology domain.

3.4. Cited Author Analysis

The corpus of research under review includes contributions from 615 authors and references to 842 cited authors. Among them, Steinmetz Nicole F, Wege Christina, and Sun Xianchao stand out with their substantial contributions to the field, authoring 58, 14, and 13 papers respectively on the topic. As depicted in Figure 3A, Steinmetz Nicole F is notably distinguished among cited authors, having initiated her foray into nanotechnology in 2006 and subsequently contributing 279 papers, with a significant focus (58 papers) on nanotechnology applications in tobacco as of December 2023. Her 2020 publication in Nature Nanotechnology, "COVID-19 vaccine development and nanoparticle pathways"[20],which has garnered 387 citations, underscores her profound impact within the nanotechnology sphere, positioning her as a highly cited author. Furthermore, Figure 3B reveals that two of the 842 co-cited authors have been referenced over 100 times, with Bruckman Michael A leading in co-citations (n=133), followed by Steinmetz Nicole F (n=102) and SHUKLA S (n=87), making them the top three most cited authors in this domain.

The collaborative network involving Steinmetz Nicole F, Chan Soo Khim, Ulrich Commandeur, among others, is notably cohesive, likely due to their affiliation with the University of California San Diego and their shared research interests. Their collective expertise in designing, developing, and testing materials and biologics derived from plant viruses for novel applications in medicine and biology elucidates their strong and enduring collaboration.

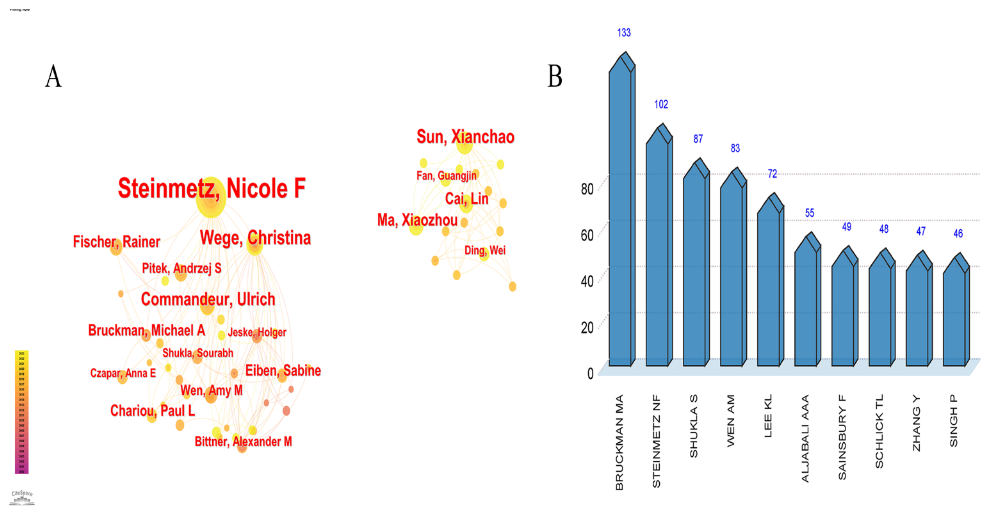

Figure 3: (A)This is the cited author graph produced by citespace, and the larger the node, the more the number of citations. (B) This is a bar chart of the top 10 most commonly cited authors produced through the website Weisheng.

3.5. Cited Journal Analysis

The period from 2000 to 2023 witnessed citations from 574 journals, with 122 journals being cited at least 50 times each. The leading journals in terms of publication volume include PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA (426 citations), SCIENCE (303 citations), and PLANT PHYSIOLOGY (298 citations). The 2023 Journal Citation Reports (JCR) indicate that out of the top 10 journals listed in Table 2 are ranked in Q1, signifying the global relevance and vibrancy of research on the impact of nanoparticles on tobacco.

ISSN 2616-5910 Vol. 6, Issue 1: 1-7, DOI: 10.25236/AJALS.2025.060101

Table 2: Top 10 Co-cited Journals related to the research of NPs on tobacco.

RANK	Citation times	Year	Journal title	JCR(2023)	IF(2023)	H-index
1	426	2000	PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA	Q1	11.1	699
2	303	2002	SCIENCE	Q1	56.9	1058
3	298	2000	PLANT PHYSIOLOGY	Q1	7.4	276
4	294	2010	PLoS One	Q2	3.7	268
5	291	2000	NATURE	Q1	64.8	1096
6	254	2000	VIROLOGY	Q3	3.7	162
7	238	2000	PLANT JOURNAL	Q1	7.2	241
8	235	2015	Frontiers in Plant Science	Q2	5.6	83
9	235	2010	ACS Nano	Q1	17.1	310
10	224	2007	NANO LETTERS	Q1	10.8	430

3.6. Keyword Co-occurrence Analysis

Utilizing VOSviewer for visualization, the keyword network and overlay maps were constructed. Figure 4A visualizes the keyword network for terms with at least 15 occurrences, organizing them into four clusters, each represented by a different color. The yellow cluster, denoting Cluster #1, focuses on the impact of nanoparticles on gene expression and proteins in tobacco, encompassing keywords such as "protein," "transgenic," and "DNA." The green cluster, or Cluster #2, is centered on the interactions between nanomaterials and plant viruses, highlighted by terms like "viral nanoparticles," "plant viruses," and "in-situ vaccination." Cluster #3, represented in blue, concentrates on efforts to thwart the tobacco mosaic virus, with keywords including "tobacco-mosaic-virus," "coat protein," and "plant virus." Lastly, the red cluster, or Cluster #4, relates to the effects of synthesized nanoparticles on tobacco growth, with keywords such as "plant-growth," "expression," "gene-expression," and "resistance."

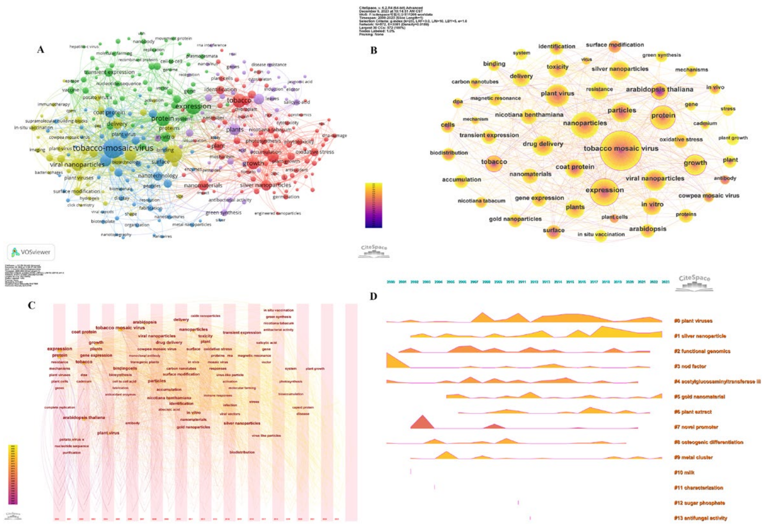

Figure 4: (A) Visualization of VOSviewer author keyword co-occurrence analysis network (T≥5). (B) Top 43 keyword occurrences. (C) The sections of keywords in the timeline represent the research hotspots of the current year. (D) Keyword clustering on the timeline.

The overlay visualization map in Figure 4B traces the temporal shifts in keyword prominence, with "tobacco mosaic virus" maintaining a consistent research interest, as indicated by its yellow nodes. Emerging keywords like "plant growth," "green synthesis," "in-situ vaccination," and "immunotherapy" hint at prospective research directions. The keyword clustering timelines in Figures 4C and 4D reveal that "silver nanoparticle" research initiated in 2002, peaked in 2018, and remains an active research area. Silver nanoparticles are recognized for their antibacterial properties, which could be leveraged to mitigate bacterial and fungal growth in tobacco, potentially enhancing tobacco storage and processing by reducing

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microbial contamination and thus preserving tobacco freshness and quality[21]. Current research efforts are directed towards utilizing silver nanoparticles to curtail the release of harmful substances in tobacco products, as demonstrated by recent studies [22-23].

4. Conclusions

Through a meticulous bibliometric scrutiny of literature on nanoparticles in to-bacco research spanning the years 2000 to 2023, this inquiry has elucidated the pre-vailing research landscape, prominent research entities, pivotal scholars, their collabo-rative dynamics, and the influential journals within this realm. The analysis underscores a burgeoning application of nanotechnology in the biological study of tobacco, particu-larly in fostering growth, enhancing resistance, disease mitigation, and genetic modi-fication, thereby yielding substantial benefits. Concurrently, with a deepening com-prehension of the potential hazards posed by nanomaterials, aspects of environmental and health safety have increasingly become integral to research agendas.

Future research directions should persist in probing the safe and efficacious de-ployment of nanotechnology, especially in nascent arenas such as tobacco virus miti-gation and the green synthesis of nanomaterials. This study accentuates the criticality of interdisciplinary collaboration and the sustained advancement of precise, efficient nanotechnological applications within agricultural science. To assure the sustainable progression of nanotechnology in tobacco research, forthcoming endeavors ought to place a heightened emphasis on the environmental ramifications and ecological safety of nanoparticles, thereby fostering a harmonious symbiosis between technological in-novation and environmental stewardship.

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