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Original article

Mapping the Intellectual Landscape of Sunflower Technological Innovations: Bibliometric Insights into Research Focus, Findings, and Future Directions

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Abstract

Sunflower (Helianthus annuus L.), a critical oilseed crop, which plays a pivotal role in addressing global food security and climate resilience challenges. The study conducted a bibliometric review of global studies on technical improvements in sunflower from 2000 to 2024. The inquiry, which used data from the Dimensions database and was displayed, using VOSviewer, contained 287 scholarly publications, indicating a significant increase in research production, with a peak of 20 articles in 2021. A positive correlation ($r = 0.68$, $p < 0.05$) was found between time and publication production, especially after 2010, indicating increased intellectual involvement in sunflower development in response to growing concerns about food security and climate resilience. Keyword co-occurrence analysis identified important themes such as yield enhancement, drought resistance, oil quality, and genetic traits; nevertheless, socio-economic and sustainability concerns were not adequately addressed. The journal Helia was identified as the primary publication source, although co-authorship networks revealed fragmented institutional cooperation and limited regional integration. More than 95% of publications were primarily about agricultural and biological sciences, with little input from environmental or social sciences. These findings highlight the need for more interdisciplinary and inclusive research methodologies to fully explore sunflower technology developments for sustainable and equitable agro-food systems, identifying considerable gaps in socio-economic research and sustainability of sunflower production.

Keywords: Agricultural Innovation Systems; Bibliometric Analysis; Sunflower production; Technological Innovations

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INTRODUCTION

The advancement of agricultural technologies has significantly influenced the global discourse on food security, climate resilience, and sustainable rural development. In the face of climate change, population pressure, and declining soil fertility, innovations in agriculture have become indispensable for improving input use efficiency and increasing crop productivity (FAO, 2022; Jayne et al., 2021; Ngoma et al., 2021). Among the major oilseed crops, sunflower has emerged as a globally significant crop due to its wide adaptability, nutritional value, and diverse economic uses. Globally, sunflower ranks as the third most important oilseed crop after soybean and rapeseed, contributing nearly 9% of total global oilseed output (DeLay et al., 2022; Inovia & Brétignières, 2020; USDA., 2022). Sunflower is primarily cultivated for edible oil, but it also provides critical by-products for livestock feed, bioenergy, and industrial raw materials (Inovia & Brétignières, 2020). Specially, sunflower kernels typically contain about 50% unsaturated lipids suitable for edible oils and biodiesel, 20–25% proteins and 35.2 mg α-tocopherol (vitamin E) per 100 g, positioning the crop as a leading natural source of antioxidant (Jebur et al., 2024; Yu et al., 2023).

The Russian Federation, Ukraine, and Argentina lead in sunflower production globally, owing to their access to large-scale mechanized farming, high-yielding seed varieties, and advanced input delivery systems (FAO, 2022; Karunathilake et al., 2023; Lyanga, 2024). In contrast, many countries in Sub-Saharan Africa and parts of Asia continue to experience low productivity of sunflower levels due to limited adoption of modern technologies, weak extension systems, and suboptimal policy support (FAOSTAT, 2021; Isinika & Jeckoniah, 2021; Masaki & Marwa, 2019). Other production constraints include lack of improved seeds varieties, inorganic fertilizers and mechanized tools (Mussa, 2020; Tibamanya et al., 2022). In Tanzania, for instance, although sunflower contributes 35% of the country's edible oil production, yields remain as low as 0.6–0.98 tons per hectare, far below the potential yield of 2–3 tons per hectare (BoT, 2017; Kamugisha et al., 2020). These yield gaps are largely attributed to the production constraints earlier stated above(Mussa, 2020; Tibamanya et al., 2022)

The last two decades have witnessed a growing global interest in the application of technological innovations in sunflower farming. Sunflower technological innovations, include scientific and practical advancements applied to sunflower cultivation, processing, or management that significantly enhance productivity, resilience, quality, or economic value. These include but are not limited to agronomic practices (e.g., intercropping, irrigation management), breeding technologies (e.g., hybrid development, drought resistance), oil quality improvements (e.g., high-oleic cultivars), precision agriculture (e.g., crop modeling, precision tools), and socio-economic innovations (e.g., contract farming, adoption-enhancing policies) (Gaviglio et al., 2021; Zozimo et al., 2023; Zymaroieva et al., 2021; Škorić et al., 2007). However, despite this growing interest, the available literature on sunflower innovation remains fragmented and unevenly distributed across regions and disciplines. Moreover, while several studies have focused on the impact of technology adoption at the farm level, there has been limited effort to systematically map the evolution of global scholarly knowledge in this domain (Mukherjee et al., 2025; Sarwosri, 2020). This fragmentation poses a challenge for researchers and policymakers seeking to understand the broader development of sunflower-related technological research and identify emerging trends and future directions.

Existing reviews on sunflower production and innovation tend to be narrow in scope, often focusing on technical or agronomic aspects at the local level (Kingu et al., 2024; Mwatawala et al., 2022) while few studies explore the intellectual landscape of the field using bibliometric methods. As such, no comprehensive bibliometric study currently exists that captures the global trajectory, intellectual structure, and collaborative networks underpinning research on sunflower technological innovations. In contrast to other oilseed crops such as soybeans and rapeseed which have attracted considerable bibliometric interest (Feng et al., 2022; Mukherjee et al., 2025; Zheng & Liu, 2022), sunflower has remained underrepresented in global research syntheses. This omission leaves a critical gap in understanding how sunflower-related technologies are being conceptualized, who the leading contributors are, and what themes are emerging as priorities in the academic literature and thus creating other frontiers of knowledge on sunflower production.

To fill this gap, this study undertook a comprehensive bibliometric analysis of research on sunflower technological innovations, with a focus on mapping the evolution of scholarly knowledge, identifying key contributors, and tracking emerging trends and scholarly research areas over the past two decades. The review aims to answer questions such as: What are the most researched topics in sunflower technological innovation? Who are the leading authors, institutions, and countries in this field? How has the research focus evolved over time? What are the existing scholarly research gaps? By addressing these questions, the study provides a quantitative and visual map of the knowledge domain, offering critical insights into the intellectual structure and dynamic evolution of sunflower innovation research. The findings will be of value to researchers, agricultural planners, development organizations, and policymakers who seek to promote evidence-based innovations in sunflower production. Furthermore, by consolidating and visualizing current trends, the study helps define future research trajectories and strategic areas of investment in sunflower technological advancement.

METHODOLOGY

This study utilized bibliometric analysis to systematically map the progression of academic knowledge and detect new trends in sunflower technological advancements from 2000 to 2024. Bibliometric analysis provides a quantitative and visual method for assessing publication outputs, citation trends, thematic frameworks, and collaborative networks, yielding a thorough overview of the intellectual landscape of a research subject (Donthu et al., 2021). To guarantee a rigorous and reproducible analysis, we integrated quantitative bibliometric techniques with qualitative content analysis to investigate research themes, methodologies, and principal findings, addressing both the structural and substantive aspects of the literature.

Data Collection Strategies

Data were obtained from the Dimensions database, a comprehensive interdisciplinary platform that indexes millions of intellectual outputs, including journal articles, conference proceedings, books, and patents. Dimensions database was chosen for its comprehensive coverage, strong citation tracking, and interoperability with bibliometric visualization tools such as VOSviewer, rendering it appropriate for capturing the global extent of sunflower research. The literature review was performed in March 2024, spanning from 2000 to 2024 to include both historical progressions and contemporary improvements in sunflower technology. Although Dimensions database offers extensive coverage, it may inadequately represent papers from regional or non-English journals, possibly constraining the exposure of research from specific areas (e.g., Sub-Saharan Africa). To address this, we verified a sample of results against other databases (e.g., Scopus) to guarantee comprehensiveness; nonetheless, only Dimensions data were utilized for the final study owing to its enhanced export functionalities.

Search Strategy and Inclusion Criteria

A systematic search strategy was established utilizing combinations of terms such as “sunflower production,” “sunflower farming,” “technological innovation,” “enhanced technologies,” “agricultural innovation,” and “economic efficiency.” Boolean operators (AND, OR) and phrase searching were utilized to enhance the search and guarantee specificity. The search was restricted to peer-reviewed journal publications published in English to emphasize high-quality, widely accessible contributions. Non-English articles, books, conference papers, and gray literature were omitted to ensure consistency and prioritize peer-reviewed research. After the application of these criteria, duplicate records and extraneous entries were meticulously examined through the assessment of titles, abstracts, and keywords. The final dataset consisted of 287 papers, chosen in alignment with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. Figure 1 presents the PRISMA flow diagram, delineating the phases of identification (n=1,234 records), screening (n=456 eligible), and inclusion (n=287 articles), thereby providing openness in the data selection process.

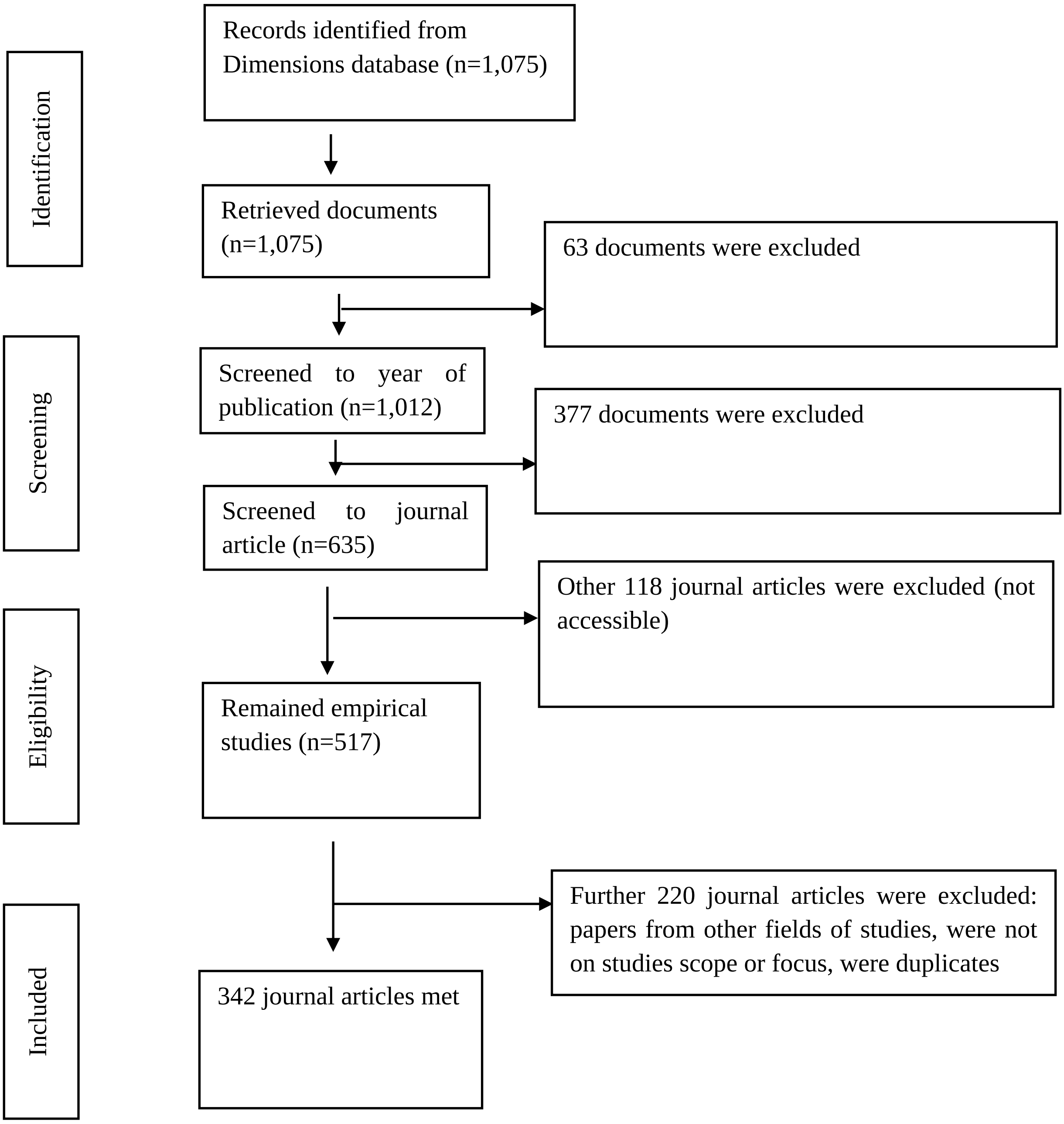

Figure 1: The Bibliometric Procedure in the PRISMA Flow Diagram.

Data Analysis and Visualization

The curated dataset was exported in CSV format from Dimensions and evaluated through quantitative and qualitative approaches. A quantitative bibliometric analysis was performed utilizing VOSviewer (version 1.6.19), a prominent tool for visualizing bibliometric networks. VOSviewer utilizes a distance-based mapping methodology, positioning things (e.g., authors, keywords) that frequently co-occur in proximity to one another, hence enabling the discernment of theme clusters and collaboration patterns. The subsequent bibliometric indicators were examined:

- **i.** Annual publishing trends to evaluate the progression of research throughout time.
- **ii.** Citation analysis to ascertain prominent writers and documents, predicated on total citations and co-citation strength.
- **iii.** Analysis of keyword co-occurrence to identify prevailing themes and developing issues, with clusters designated according to significant keywords.
- **iv.** Co-authorship and institutional collaboration networks to delineate academic connection and regional leadership.
- **v.** Conduct a source impact study to assess the influence of journals on sunflower research.

A qualitative content analysis was performed on a selection of 30 high-impact articles (determined by citation counts) and 20 recent articles (2020–2024) to get deeper insights regarding research emphasis and major discoveries. This entailed coding abstracts and complete texts for study inquiries (e.g., yield optimization, genetic enhancement), procedures (e.g., field trials, modeling), and significant discoveries (e.g., specific breakthroughs in hybrids or agronomic practices). This mixed-methods approach guaranteed that the study transcended just descriptive metrics to encompass the significant contributions of the literature.

Methodological Considerations

The selection of bibliometric indicators was informed by the study’s aims to delineate the intellectual framework, recognize important contributions, and monitor theme progression. Co-authorship and keyword analyses were emphasized to uncover collaboration patterns and research interests, whilst citation analysis underscored significant works. Nonetheless, limitations encompass the possible bias favoring English-language publications, which may inadequately represent studies from areas such as Eastern Europe or Asia, where sunflower is a significant crop. Furthermore, dependence on Dimensions database may overlook specialized journals not included in the database. To improve robustness, thematic clusters and major findings were cross-validated through discussions within the study team to ensure precise interpretation.

Visualization and Analysis

Thematic clusters were visually analyzed using VOSviewer maps, where node sizes represented frequency (e.g., citation counts, keyword occurrences) and link thickness denoted co-occurrence strength. Color coding was employed to signify chronological gradients (e.g., publication years) or thematic associations. Qualitative inputs from content analysis were incorporated into the interpretation of clusters to enhance the understanding of research focuses and findings, assuring consistency with the study's objective of mapping knowledge evolution and emerging trends.

Study Limitations

This study provides a thorough bibliometric analysis of global sunflower technological innovations; however, several limitations must be recognized. First, the analysis only used the Dimensions database. This database has a lot of peer-reviewed literature and works well with visualization tools like VOSviewer, but it might not include all the studies that are important, especially those from journals that are only in English or that are only in a certain area. As a result, some important researchers and important topics, might not be represented enough or at all in the dataset. Second, the search strategy used was based on broad terms that had to do with "sunflower" and "technological innovation." Consequently, highly specialized studies employing molecular markers, genetic maps, or genomic sequencing etc. that may not explicitly utilize the term "innovation" were not retrieved, despite their representation of significant technological advancements. This lexical constraint emphasizes the balance between search specificity and disciplinary comprehensiveness. Third, our analysis did not include gray literature, preprints, or conference proceedings, which could be important sources of new research, especially in the Global South. Lastly, the choice to limit the study to English-language publications may have unintentionally omitted significant research published in other languages, especially from Eastern Europe, South America, or Asia. These limitations collectively indicate that although the study encompasses extensive intellectual trends, it fails to provide a comprehensive overview of all innovation categories in sunflower research. Future bibliometric reviews could enhance their rigor by triangulating data from various databases (e.g., Scopus, Web of Science).

RESULTS AND DISCUSSION

Temporal Trends in Sunflower Technological Innovations Research

The temporal trends in sunflower technological innovations research from 2000 to 2024 reveal a complex narrative of scholarly engagement. The analysis of publication data indicates a non-linear growth trajectory characterized by fluctuations in output. The initial phase from 2000 to 2008 was marked by modest publication rates. This period coincided with a predominant focus on staple crops, such as maize, rice, and wheat, which overshadowed oilseed crops like sunflower. Consequently, research during this formative stage was largely descriptive and localized, lacking the technological innovation and economic efficiency that would later characterize the field (Akbari et al., 2020; Fuglie et al., 2020; Mamgbi Zozimo et al., 2023; Vretenar, 2025).

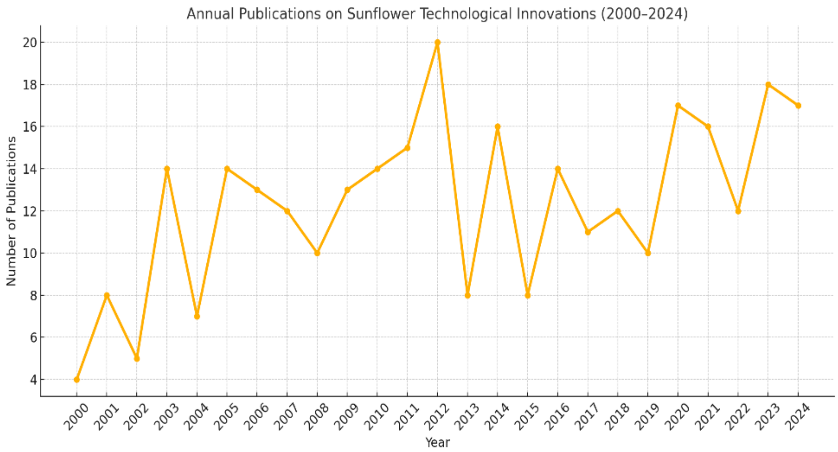

Figure 2. Annual publication trends on sunflower technological innovations (2000–2024)

The subsequent period from 2010 to 2012 saw a gradual increase in publication output, reflecting a transitional phase in which sunflower began to gain recognition for its potential role in enhancing edible oil self-sufficiency and diversifying rural incomes. The research during this time began to incorporate improved agricultural practices, such as the use of enhanced seed varieties and synthetic fertilizers, although it often lacked comprehensive analyses of adoption dynamics and efficiency outcomes (Alfred & Zawedde, 2022; Tibamanya et al., 2021). Sunflower exhibits substantial macronutrient demands, with nitrogen (N) to support vegetative growth and biomass buildup, phosphorus (P) for root development and seed formation, and potassium (K) for water regulation, disease resistance, and oil quality (Put tha et al., 2023). NPK fertilizers are synthetic, water-soluble blends providing these macronutrients in precise, balanced ratios allowing rapid absorption. Organic fertilizers, derived from sources like compost, manure, or vermicomposting, release nutrients slowly through microbial decomposition, improving soil structure and biological activity while supporting long-term soil health and sustainability (Puttha et al., 2023). The peak of 20 publications in 2012 can be linked to an increasing global emphasis on climate-resilient crops and sustainable agriculture practices, as well as increased financing for research aimed at addressing climate change adaptation (Alvar-Beltrán et al., 2021; Shreya Kar et al., 2021; van Dijk et al., 2024). For instance, NSA, (2012) of the United States allocated targeted grants in 2012, thereby supporting distinct initiatives centered on yield optimization, disease diagnostics, and hybrid vigor enhancement. However, the subsequent decline in 2013 to just 8 publications underscores a critical challenge in agricultural research: the reliance on donor-driven projects that are often time-bound, rather than fostering long-term institutional investment.

The period from 2014 to 2019 exhibited a stabilization in publication output, with annual counts consistently ranging from 10 to 16. This era was characterized by a deeper engagement with concepts such as technical and resource use efficiency, particularly among smallholder farmers in Sub-Saharan Africa and South Asia (Kumar et al., 2024; Mwatawala et al., 2022; Zozimo et al., 2023). The post-

2020 phase marks a renewed momentum in sunflower research, with publication numbers exceeding 15 annually and reaching 18 in 2024. This renaissance aligns with global agricultural disruptions, including the COVID-19 pandemic and the geopolitical tensions stemming from the Russia-Ukraine conflict, which have underscored vulnerabilities in global edible oil supply chains and rekindled interest in domestic sunflower production (EFECA, 2022; FAO & WPF, 2021; GAIN, 2021; HLPE, 2023). During this period, research diversified to encompass digital innovations, contract farming models, and inclusive value chain approaches, indicating a shift towards more holistic and systems-oriented inquiries.

The observed correlation between time and publication output ($r = 0.68$, $p < 0.05$) from 2011 to 2024 indicating a significant upward trend in scholarly engagement with sunflower technological innovations. This highlights the increasing recognition of sunflower as a strategic crop within global agricultural research and policy discourse. This progression suggests a transition from niche breeding-focused studies to multidisciplinary innovations that integrate genetics, agronomy, and system optimization.

Table 1: Publication Trends and Correlations in Sunflower Technological Innovation Research

Time Period	Publication Growth	Correlation (r)	p-value
2000 - 2010	Low (< 10 papers/year)		
2011 - 2019	Moderate (10–15/year)	0.68	< 0.05
2020 - 2021	Peak (20 papers in 2021)		
2022 - 2024	Stable (14–18/year)		

However, while the volume of publications has increased, it is imperative to critically assess whether this growth is accompanied by enhanced research quality, diversity, and practical relevance. Are recent studies addressing emerging frontiers such as climate-smart practices, circular bio-economy, and digital agro-tech in sunflower farming, or are they merely reiterating previous agronomic trials in varied contexts? Furthermore, the recent growth appears to be more reactive, driven by crises rather than strategic planning. The reactive nature of research spikes—such as the surge following global food crises—raises concerns about the resilience and foresight of sunflower research agendas. For sunflower to be fully integrated into sustainable agricultural strategies, especially in low- and middle-income countries, a more proactive and sustained research investment framework is required.

Leading Authors in Citations

The analysis of co-authorship networks among the most cited authors in sunflower technological innovations research from 2000 to 2024 reveals significant insights into the intellectual structure and collaborative dynamics of this field. The visualization presented in Figure 3 illustrates a network where node size corresponds to the total number of citations per author, while node color indicates the average year of publication, thereby providing a temporal context to the scholarly contributions. Central to this network is Gerald J. Seiler, whose extensive citation record and collaborative links underscore his pivotal role in advancing sunflower genetic improvement and breeding methodologies. Seiler's contributions, particularly in the domains of wild sunflower species, germplasm conservation, and hybrid development, are foundational to contemporary sunflower innovation (Pilorgé, 2020; Seiler et al., 2017).

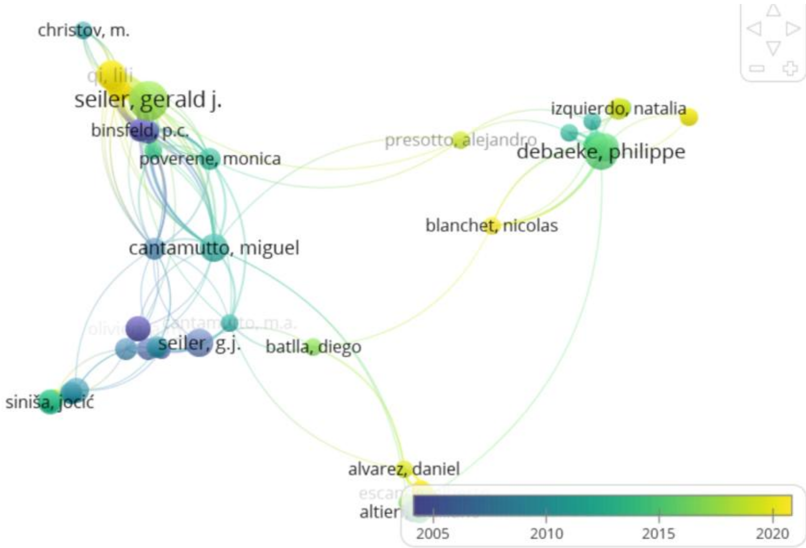

Figure 3. Co-authorship network of researchers in sunflower technological innovation studies (2000–2020)

The analysis further identifies other prominent contributors such as Cantamutto, Miguel, Poverene, Monica, and Debaeke, Philippe, who have established strong regional clusters, particularly in Argentina and Europe. The collaborative efforts of Cantamutto and Poverene are particularly noteworthy, as they focus on developing hybrid sunflower varieties that are adapted to local conditions, addressing critical challenges such as soil fertility, water scarcity, and climate variability. Their interconnectedness with researchers like Batlla, Diego, and Binsfeld illustrates a robust research ecosystem that has significantly influenced agronomic practices and technological advancements in Latin America. In Europe, Debaeke's research on agronomic modeling and drought resilience has gained prominence, with newer collaborators such as Izquierdo, Natalia, and Blanchet, Nicolas contributing to the discourse on sunflower adaptation to climate change and sustainable agricultural practices (Debaeke et al., 2020; Zymaroieva et al., 2021).

The temporal gradient indicated by the color of the nodes—from blue (early 2000s) to yellow (post-2015)—suggests a dual narrative: while established scholars have maintained their prominence, a new generation of researchers, exemplified by Alvarez, Daniel, and Presotto, Alejandro, is emerging. These newer scholars are engaging with advanced biotechnological and genomic methodologies, yet their citation counts remain modest due to their relatively recent entry into the field (Presotto et al., 2017). This evolving landscape highlights a geographical concentration of influential authors predominantly in the Global North and parts of Latin America, with a notable lack of citation impact from Sub-Saharan Africa and South Asia—regions that are increasingly important for sunflower cultivation (Mpenda & & Mgen, 2021; Tibamanya et al., 2021). This disparity raises concerns regarding the barriers faced by scholars from these regions, including economic and institutional constraints that hinder their visibility and publication opportunities in high-impact journals, a sentiment echoed by (Tandon et al.,2021). Moreover, the dominance of a select few authors in the citation landscape underscores a potential limitation in the diversity of perspectives and innovation pathways within the field. While the foundational contributions of these scholars are invaluable, the reliance on a narrow group may stifle broader intellectual engagement and innovation. However, the emergence of newer nodes, particularly those focused on interdisciplinary and climate-related research, signals a gradual shift towards thematic diversification.

Key Research Focuses and Methodologies

This analysis critically examines the research focuses and methodologies of 287 peer-reviewed articles addressing technological advancements in sunflower cultivation from 2000 to 2024. The thematic organization of the research is derived from a keyword co-occurrence analysis, categorizing the literature into three primary clusters: agronomy and yield, genetics and resistance, and oil quality and genotype-environment interaction. This framework not only elucidates the intellectual priorities within sunflower research but also highlights significant methodological deficiencies that limit the field’s responsiveness to broader socio-ecological challenges, including food security, climate resilience, and equitable technology dissemination.

The agronomy and yield cluster is primarily concerned with enhancing sunflower productivity, particularly in resource-constrained and climate-sensitive regions. Research in this domain investigates various agronomic strategies, such as intercropping, fertilizer application, and irrigation management, to optimize yields and resource efficiency. Notable studies, such as those by Tibamanya et al.(2022) and Debaeke et al.(2020), emphasize the importance of integrated soil fertility management and agronomic modeling, respectively. However, the methodologies employed—predominantly field trials (40%) and simulation models (15%)—exhibit a significant limitation in their generalizability across diverse agro ecological contexts. The reliance on localized trials, coupled with a conspicuous absence of advanced digital tools like precision agriculture and remote sensing, underscores a methodological shortcoming that could otherwise enhance agronomic innovations.

Table 2: Key Research Focus and Methodologies in Sunflower Technological Innovations

Thematic Cluster	Research Foci	Methodologies	Representative Studies
Agronomy and Yield	Optimizing yields through intercropping, fertilizer use, and modeling	Field trials (40%), simulation models (15%)	Debaeke et al. (2020), Tibamanya et al. (2021), Kamugisha et al. (2020a)
Genetics and Resistance	Developing stress-resistant hybrids using wild relatives and genomic selection	Genomic analysis (30%), breeding trials (25%)	Seiler et al. (2017), Presotto et al. (2017), Dimitrijevic (2018)
Oil Quality and Genotype-Environment Interaction	Enhancing oil quality through genotype selection and environmental analysis	Multi-location trials (20%), statistical modeling (15%)	Mpenda and Mgen (2021), Zymaroieva et al. (2021)
Socio-Economic Factors	Identifying barriers to technology adoption	Surveys, econometric analysis (<5%)	Tibamanya et al. (2022)

In the genetics and resistance cluster, the focus shifts to developing sunflower cultivars that exhibit resilience to both abiotic stresses (e.g., drought and salinity) and biotic threats (e.g., pests and diseases). Research contributions from Seiler et al.(2017) and Presotto et al.(2017) highlighted the utilization of wild relatives and crop-wild hybridization to enhance genetic diversity and stress tolerance. The methodologies in this cluster are characterized by genomic analysis (30%) and field-based breeding trials (25%), reflecting a strong emphasis on molecular and experimental techniques. While these approaches have led to significant advancements, including the commercialization of drought-resistant hybrids, they often overlook participatory breeding practices that could incorporate farmer preferences and indigenous knowledge—an oversight particularly detrimental in regions like Sub-Saharan Africa, where smallholder needs are inadequately represented.

The oil quality and genotype-environment interaction cluster aims to enhance the nutritional and commercial value of sunflower oil by examining the interplay between genotypes and environmental factors. Studies by Mpenda & Mgen (2021) and Zymaroieva et al. (2021) illustrate the focus on developing high-oleic sunflower cultivars and assessing the impact of soil and climatic variables on oil quality. However, the predominant methodologies—multi-location trials (20%) and statistical modeling (15%)—often neglect socio-economic considerations, such as the environmental impacts of intensive farming and the economic viability of high-oleic cultivars for smallholder farmers. This oversight limits the applicability of findings in low-income contexts, where market access and cost are critical barriers.

A notable deficiency in the literature is the lack of socio-economic and policy-oriented research, with less than 5% of studies addressing technology adoption dynamics, market linkages, or institutional support. While Tibamanya et al. (2022) provide insights into barriers to the adoption of improved varieties in Tanzania, such studies remain rare. The methodological predominance of field trials and modeling—over 70% of the analyzed studies—restricts the ability of field engage with complex socio-ecological systems. Emerging methodologies, such as econometric analysis, participatory research, and the integration of digital tools, are conspicuously absent, revealing a disciplinary bias favoring agronomic and biological sciences. This bias, coupled with a spatial concentration of research in North America and Europe, raises critical questions regarding epistemic inequality and the relevance of findings to regions like Sub-Saharan Africa and South Asia, where sunflower cultivation is increasingly significant. Thus, a more inclusive and interdisciplinary approach is essential to align sunflower research with global agricultural objectives and address the pressing challenges of food security and climate change.

Co-Citation Landscape of Sunflower Technological Innovations

The co-citation network of the most cited documents in sunflower technological innovations, as depicted in Figure 4, offers a critical lens through which to examine the intellectual architecture of this field. This visual representation not only elucidates the thematic orientations and epistemic communities but also highlights the influential contributions that have shaped research priorities over the past two decades. The size of each node corresponds to citation frequency, while the links denote co-citation strength, revealing the interconnectedness of scholarly works. The color-coded clusters signify thematic coherence, while inter-cluster linkages suggest interdisciplinary dialogues that are pivotal for knowledge bridging.

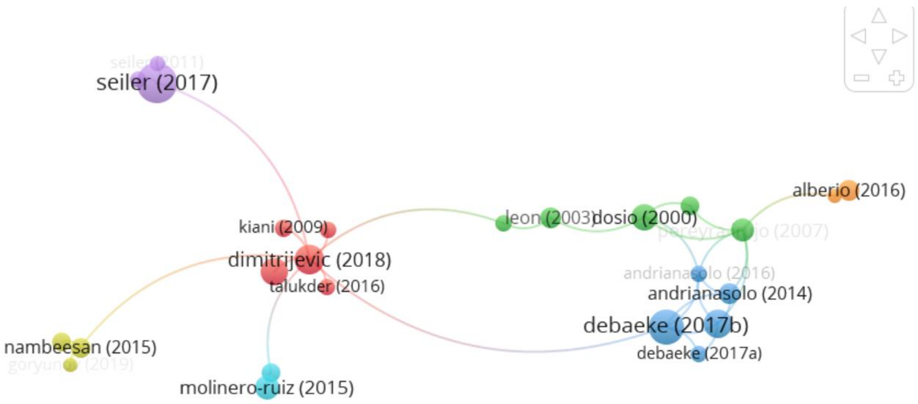

Figure 4. Network of the most cited documents on sunflower technological innovations (2000–2020)

At the core of this scholarly network is Seiler et al. (2017) influential work, which stands out as the most frequently cited reference in the field. His comprehensive examination of sunflower wild relatives, genetic resources, and breeding systems has provided a critical foundation for subsequent research. Seiler's prominence highlights the continued importance of classical plant breeding in driving sunflower innovation, even as modern biotechnological approaches gain traction. The widespread relevance of his study extends beyond plant breeders and agronomists to researchers focused on environmental adaptation. This central role is further supported by (Kombe et al., 2017), who note that African sunflower research continues to depend heavily on conventional breeding materials, often derived from international gene pools.

Surrounding this core are influential works by Dimitrijevic & Horn, (2018), Škorić (2016) and Debaeke et al. (2020), which collectively form a high-impact cluster focused on abiotic stress management. These studies investigate the physiological responses of sunflowers to environmental stressors such as drought, salinity, and heat, utilizing experimental field and greenhouse trials. The prominence of this cluster reflects an urgent need for climate-resilient crops, particularly in regions where sunflower cultivation is promoted under marginal and rain-fed conditions. As articulated by Tibamanya et al.(2021), the success of sunflower in Tanzania's edible oil strategy is contingent not only on seed availability but also on its performance under ecological constraints.

A further cluster, led by Debaeke et al., (2020) and Andrianasolo et al. (2016), adopts a systems-level perspective, analyzing sunflower productivity through agronomic modeling and yield simulation. These studies exemplify a methodological shift towards decision-support tools that enable farmers and policymakers to optimize land use under varying climatic conditions. The co-citation of these works with those in stress physiology signifies a growing integration of crop ecology and modeling frameworks, indicative of the field's methodological maturation. Zymaroieva et al.(2021), highlight the critical importance of simulating sunflower performance under diverse soil and rainfall scenarios for scaling production in climate-vulnerable regions.

Conversely, the analysis reveals a thematic maturity that is unevenly diversified. While the dominance of physiology, breeding, and modeling studies indicates a robust technical foundation, there is a conspicuous absence of socio-economic, policy, or participatory research. The lack of documents addressing farmer adoption behavior, value chain innovation, or gender dynamics in technology uptake reflects a persistent marginalization of human-centered perspectives in sunflower innovation discourse. This oversight is concerning, given the increasing recognition of the importance of these factors in successful technology diffusion (Mwangi & Kariuki, 2015; Ngoma et al., 2021).

Moreover, the geographical skewness of the most cited documents, predominantly concentrated in North America and Europe, raises critical questions about epistemic inequality. Despite the promotion of sunflower cultivation in Sub-Saharan Africa and Asia, scholarship from these regions remains underrepresented in global citations. This imbalance not only limits the visibility of context-specific innovations but also risks perpetuating a narrow, universalist model of technological change that may not align with the socio-ecological realities of emerging production zones (Tibamanya et al., 2021).

Thematic Landscape of Sunflower Technological Innovations

The co-occurrence analysis of keywords extracted from scholarly publications on sunflower technological innovations, as visualized in Figure 5 using VOSviewer, provides a comprehensive overview of the thematic structure and intellectual connections within this field. The network delineates three primary clusters—agronomy and yield, genetics and resistance, and oil quality and genotype-environment interaction—each representing distinct strands of inquiry. The centrality of the term "sunflower" underscores its pivotal role in linking various research dimensions, including production goals, genetic enhancement, and agronomic performance. The red cluster, characterized by keywords such as "yield," "growth," and "treatment," indicates a strong agronomic focus, primarily centered on field experiments assessing the impact of various agronomic practices on sunflower productivity. This aligns with the findings of Liampawe, (2019), who advocate for improved agronomic practices as vital for optimizing sunflower yields, particularly in resource-limited settings. The dense interconnections within this cluster reinforce the notion that yield remains the predominant metric of performance, thus reflecting a productivity-centric perspective prevalent in existing research.

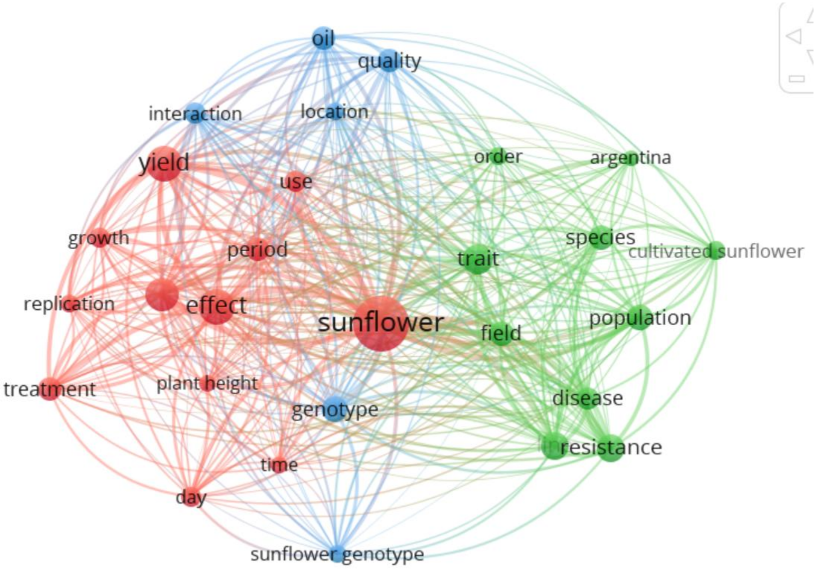

Figure 5: Keyword Co-occurrence Network of Sunflower Technological Innovations Research (2000–2024)

Conversely, the green cluster, which encompasses terms like "trait," "resistance," and "species," delves into the genetic and breeding aspects of sunflower research. This thematic focus resonates with the works of Seiler et al.(2017) and Debaeke et al (2020), who emphasize the importance of genetic improvement for enhancing stability and resilience in sunflower crops. The inclusion of keywords related to biodiversity, such as "population" and "species," highlights an ongoing interest in leveraging genetic diversity for sustainable productivity and effective disease management, as argued by (Kombe et al., 2017). The blue cluster, featuring keywords like "oil," "quality," and "interaction," reflects a growing emphasis on oil quality assessment and genotype-environment interactions. This thematic area is increasingly relevant in light of rising consumer demand for healthier edible oils, as noted by (Mpenda & Mgen, 2021). The focus on environmental factors influencing oil quality indicates a methodological shift towards multi-location trials and modeling, which are essential for understanding the adaptability of sunflower genotypes across diverse agro-ecological contexts.

However, a critical examination of the keyword co-occurrence map reveals significant thematic gaps. Notably absent are socio-economic and institutional keywords such as "adoption,"diffusion," "farmer," "policy," and "value chain." This omission underscores a prevailing emphasis on biophysical and genetic dimensions of sunflower innovation, often at the expense of understanding the socio-economic and systemic contexts that facilitate or hinder the adoption of technological advancements. The lack of attention to these dimensions is concerning, particularly in light of calls for integrated approaches that encompass both technological performance and the behavioral, institutional, and policy frameworks necessary for effective scaling (Ngoma et al., 2021).

Furthermore, emerging domains such as digital agriculture, climate-smart practices, and precision farming are notably underrepresented, indicating a disconnect between current research trajectories and global agricultural innovation trends. The absence of keywords related to environmental sustainability, such as "soil health," "carbon," and "ecosystem," is particularly alarming given the pressing need for agricultural systems to adapt to climate and environmental challenges.

Co-authorship and Institutional Collaboration Networks in Sunflower Technological Innovations

The co-authorship network of institutions engaged in sunflower technological innovations research, as depicted in Figure 6, reveals significant insights into inter-institutional collaboration and regional leadership in this field. Each node in the network represents an institution, with its size correlating to publication output and the thickness of connections indicating the strength of collaborative relationships. The color-coded clusters signify distinct collaborative groups, while the proximity of nodes reflects the frequency and intensity of co-authorship ties. The analysis indicates a sparse yet structured network, dominated by a few key institutions. The National Agricultural Technology Institute (INTA) of Argentina emerges as a pivotal player, demonstrating robust collaborative ties with both national and international research centers. Its close association with Universidad Nacional del Sur underscores Argentina's consolidated research infrastructure in sunflower improvement, agronomy, and breeding—areas frequently highlighted in high-impact publications. These institutions serve as regional anchors for sunflower research in South America, focusing on critical themes such as genetic diversity and drought resilience.

Figure 6. Co-Authorship and Institutional Collaboration Network on Sunflower Technological Innovations (2000–2024)

In contrast, North American institutions like the Edward T. Schafer Agricultural Research Center and Iowa State University exhibit a more linear and less densely clustered network. Their research contributions are primarily concentrated on seed biotechnology and oilseed quality, areas where U.S. institutions have historically excelled, particularly through USDA-supported initiatives. The presence of Iowa State University, a leading agricultural institution, suggests a strong academic influence in commercial hybrid research. However, the limited density of their collaborative network indicates a potentially insular structure, possibly aligned more with industry partnerships than with broader international academic collaboration. Moreover, the Universidad Nacional del Sur plays a crucial role as a bridge between Latin American and other research clusters, facilitating South-South knowledge exchange. This is particularly significant for sunflower research, which, despite its global cultivation, often lacks the comprehensive research attention afforded to staple crops. The network's fragmentation is concerning, particularly given the absence of institutions from Africa, Asia, and Eastern Europe, regions that contribute significantly to global sunflower cultivation and consumption. This lack of representation highlights a structural imbalance in knowledge production and scholarly visibility, with institutions from Sub-Saharan Africa and South Asia either producing less internationally recognized research or being systematically marginalized in collaboration networks.

The low density of the network further underscores the absence of sustained multi-institutional projects that could drive innovation across borders. While institutions like INTA and Iowa State have made substantial contributions, the weak co-authorship ties among diverse institutions suggest an underutilization of collaborative potential. In light of pressing transdisciplinary challenges such as climate adaptation and food security, this fragmentation poses a significant barrier to the advancement and relevance of scientific innovations in sunflower research.

Scholarly Landscape of Sunflower Technological Research

The examination of scholarly journals and publication venues in sunflower technological research reveals a complex co-citation network that underscores the intellectual dynamics within this field from 2000 to 2024. The analysis, illustrated in Figure 7, employs a visual representation where nodes signify journals, with their size correlating to citation frequency, link thickness indicating co-citation strength, and color clusters denoting thematic affiliations. This methodological approach elucidates the most influential sources shaping the discourse surrounding sunflower innovations. Prominently, the journal “Helia” emerges as the preeminent publication, characterized by its extensive citation and central positioning within the network. Renowned for its comprehensive focus on sunflower science—including breeding, physiology, agronomy, biotechnology, and pest resistance—“Helia” serves as a critical intellectual hub. Its significance is corroborated by previous studies (Joci´c et al., 2020; Kaya & Tan, 2029), which highlight its dual role in disseminating original research and critical reviews, thereby reinforcing its status as a cornerstone of sunflower scholarship.

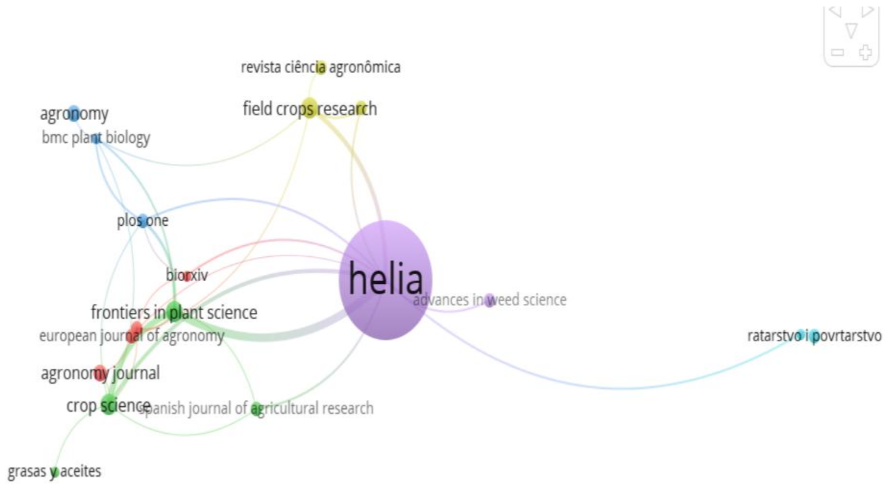

Figure 6. Journal co-citation network in sunflower technological innovations research (2000–2024).

Adjacent to “Helia”, journals such as “Field Crops Research”, “Crop Science”, “Agronomy Journal”, and “Frontiers in Plant Science” form a tightly-knit cluster that emphasizes field-based agronomic research and genotype-environment interactions. These publications collectively address essential topics such as plant-soil interactions and environmental adaptability, which are vital for developing resilient sunflower production models across diverse agroecological contexts (Dimitrijevic & Horn, 2018; Mpenda & & Mgen, 2021). The co-citation between “Field Crops Research” and “Helia” illustrates a synthesis of crop-specific and systems-level perspectives, particularly concerning traits like drought tolerance and hybrid vigor. Moreover, the emergence of open-access and interdisciplinary journals, including “Frontiers in Plant Science”, “Plos ONE”, “BioRxiv”, and “BMC

Plant Biology", signals a transformative shift towards genomics-enabled crop improvement and rapid dissemination of research findings. This trend reflects an evolving landscape in plant sciences, where early-stage research is increasingly shared through preprints, thereby accelerating knowledge transfer.

Conversely, smaller journals such as "Revista Ciência Agronômica" and "Grasas y Aceites" provide regionally focused insights but exhibit limited global citation impact, indicating a potential disconnect from mainstream international scholarship. Additionally, the peripheral positioning of journals like "Ratarstvo i povrtarstvo" and "Advances in Weed Science" suggests that critical themes such as weed management remain underexplored in sunflower innovation literature, despite their relevance to yield dynamics. While the centrality of "Helia" signifies a robust knowledge hub, the reliance on a narrow range of journals raises concerns regarding intellectual insularity and the potential neglect of interdisciplinary perspectives, particularly in areas intersecting with economics, policy, and sustainability. This observation highlights a persistent bias towards agronomic and biological sciences, underscoring the need for a more inclusive approach to agricultural innovation that embraces diverse disciplinary insights (FAO, 2022; Jayne et al., 2021)

Disciplinary Imbalance in Sunflower Technological Innovation Research

The analysis of sunflower technological innovation research, as illustrated by the Australian and New Zealand Standard Research Classification (ANZSRC, 2020), reveals a pronounced disciplinary bias towards Agricultural, Veterinary, and Food Sciences, which constitutes an overwhelming 83.9% of the total publications (342). This singular focus underscores the historical significance of sunflowers as a vital oilseed crop, particularly in terms of economic and food security (Kamugisha et al., 2020; Seiler et al., 2017).

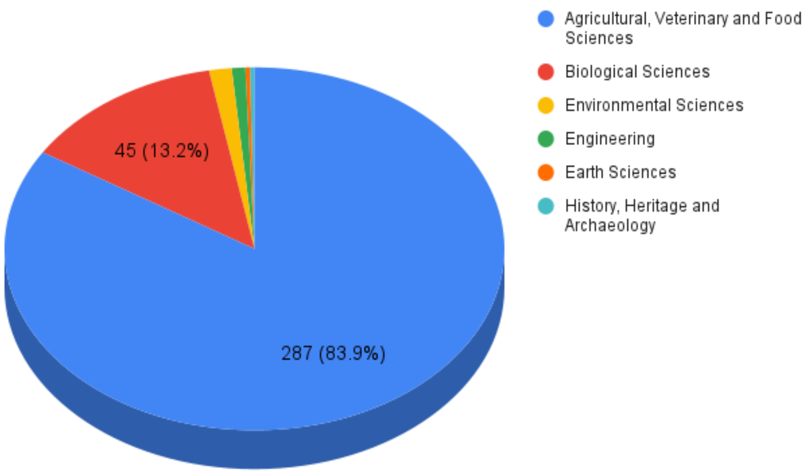

Figure 7. Distribution of publications by Fields of Research in sunflower technological innovation (2000–2024).

The research predominantly addresses genetic enhancement, agronomy, pest management, seed quality, and oil extraction efficiency, aligning closely with national agricultural policies and international development objectives, especially in sunflower-centric nations like Tanzania, Argentina, and Ukraine (Mpenda & Mgen, 2021). Conversely, the contributions from Biological Sciences, accounting for only 13.2% (45 publications), while essential for advancing plant genetics and stress physiology, highlight a critical gap in the application of these findings within real-world agricultural contexts. The limited engagement with Environmental Sciences raises significant concerns regarding the sustainability of sunflower cultivation, particularly in light of the pressing need for climate-smart agricultural practices (FAO, 2022). The scant research linking sunflower farming to soil health, biodiversity, and ecosystem services indicates a troubling oversight, especially as sunflower cultivation expands into ecologically vulnerable regions.

Moreover, the absence of contributions from Engineering and Earth Sciences reveals methodological deficiencies that could otherwise enhance sunflower cultivation through innovations in mechanization, irrigation, and geospatial modeling. This lack of interdisciplinary collaboration restricts the potential for applying precision agriculture techniques that could optimize resource use and productivity. Equally alarming is the total neglect of social sciences, which are crucial for understanding the socio-economic dynamics influencing the adoption of agricultural innovations.

Research has consistently highlighted the importance of market linkages, policy frameworks, and institutional support in facilitating the uptake of sunflower technologies, particularly among smallholder farmers (Tibamanya et al., 2022). Furthermore, the omission of historical and indigenous knowledge systems from the discourse reflects a broader epistemic limitation within the field. Incorporating these perspectives could enrich participatory breeding and contextual adaptation strategies, fostering a more holistic approach to sunflower research. The current trajectory, which prioritizes productivity metrics over comprehensive, people-centered outcomes, risks perpetuating a technocratic model that fails to address the complexities of agricultural innovation in diverse socio-economic contexts. Thus, a more integrated and interdisciplinary approach is imperative for advancing sunflower research in a manner that is both sustainable and equitable.

Research Gaps in Sunflower Technological Innovations

The analysis of sunflower technological advancements reveals critical research gaps that hinder the effective utilization of this vital oilseed crop in addressing global agricultural challenges. A review indicates significant deficiencies in thematic focus, methodological approaches, and regional representation. One of the most pronounced gaps identified is the insufficient emphasis on socio-economic and policy-oriented research. While existing studies have explored barriers to the adoption of improved sunflower varieties—such as limited seed access and inadequate extension services—there is a notable scarcity of research investigating critical factors such as farmer behavior, gender dynamics, market connections, and institutional frameworks. This lack of inquiry is particularly concerning given the substantial role women play in sunflower cultivation in Sub-Saharan Africa, as highlighted by Isinika and Jeckoniah, (2021). Furthermore, the absence of research on policy impacts, including subsidies and trade regulations, obstructs the development of supportive frameworks necessary for fostering innovation in sunflower production.

Sustainability-related research is another significant deficiency, with a conspicuous neglect of environmental impacts, soil health, and ecosystem services. Despite the relevance of terms such as "soil health," "carbon sequestration," and "biodiversity" to sunflower productivity, these concepts are notably absent from the literature, as indicated by keyword co-occurrence analyses. Agronomic studies tend to focus predominantly on yield optimization without adequately addressing the long-term environmental consequences of intensive agricultural practices, such as soil degradation and excessive water use. Additionally, the potential of sunflower by-products for bioenergy and circular bio-economies remains underexplored, thereby limiting opportunities to enhance the sustainability profile of sunflower cultivation in the context of global agricultural systems that seek to balance productivity with ecological integrity.

Table 3: Research Gaps in Sunflower Technological Innovations

Gap Category	Description	Implications	Potential Research Questions
Socio-Economic and Policy Research	Limited studies (<5%) on adoption barriers, gender dynamics, or policy frameworks	Hinders technology uptake and equity, especially for smallholders	How do gender and market access influence adoption of improved varieties? What policies enhance technology diffusion?
Sustainability and Environmental Impacts	Minimal focus on soil health, carbon sequestration, or by-product utilization	Limits alignment with climate-smart agriculture and sustainability goals	How can sunflower technological innovations enhance soil health or bioenergy production?
Methodological Diversity	Overreliance on field trials and modeling; lack of digital or participatory methods	Restricts exploration of complex socio-ecological systems	How can precision agriculture optimize sunflower yields? What role can participatory research play in breeding?
Regional Representation	Underrepresentation of Sub-Saharan Africa and South Asia (<10% of studies)	Reduces applicability in key cultivation regions	How can research capacity in the Global South be strengthened?

Methodologically, the literature exhibits a concerning over-reliance on field trials and modeling, which, while providing valuable insights into agronomic and genetic advancements, are insufficient for addressing the complexities of socio-ecological systems. Emerging methodologies, including participatory research, econometric analysis, and the integration of digital tools such as remote sensing and machine learning, are largely absent. This methodological homogeneity restricts the field's ability to explore interdisciplinary inquiries, such as how digital technologies can enhance smallholder productivity or how policy interventions can alleviate barriers to technology adoption. Geographically, the literature is disproportionately concentrated in North America and Europe, with Sub-Saharan

Africa and South Asia—regions critical for sunflower production—accounting for less than 10% of the articles reviewed. This epistemic disparity not only diminishes the relevance of findings in areas where sunflower cultivation is essential for food security but also perpetuates a techno centric framework that overlooks the socio-economic realities faced by smallholder farmers.

CONCLUSION

This bibliometric study provides a systematic overview of the global research landscape on sunflower technological innovations over the past two decades. The findings indicate a steady upward trajectory in publication output, with a marked surge between 2020 and 2021, reflecting increased global interest in crop resilience, food security, and sustainable oilseed production systems. The positive correlation between time and research output affirms the expanding recognition of sunflower as a strategic crop in the face of climate variability and rising edible oil demands. The analysis identified key contributors, with *Helia* emerging as the dominant journal and a small number of highly cited authors and documents shaping the intellectual core of the field. Co-authorship and institutional collaboration networks, however, reveal significant fragmentation, with limited integration between regions—particularly across the Global South. This underscores the need for more inclusive and equitable research partnerships that bridge disciplinary, institutional, and geographic divides.

Thematic analysis highlights an overwhelming focus on agronomic and genetic traits—such as yield improvement, drought tolerance, and oil quality—while critical areas such as technology adoption, environmental sustainability, market integration, and socio-economic impact remain underrepresented. The disciplinary mapping further confirms this imbalance, with agricultural and biological sciences accounting for the vast majority of publications, and minimal contributions from environmental, social, and policy-oriented fields. While the field of sunflower technological innovation research has made notable strides, it remains largely technocentric and fragmented. To fully realize the potential of sunflower as a climate-resilient and economically inclusive crop, future research must embrace transdisciplinary approaches that integrate agronomy, ecology, economics, and social science. Strengthening South–South and cross-continental collaboration, investing in underrepresented regions, and diversifying research themes will be essential to advance innovations that are not only scientifically robust but also socially relevant and scalable in diverse agroecological contexts.

CRediT authorship contribution statement

Erasto Abraham: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing: **Salma Khatibu Kifile** Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing.

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REFERENCES

Akbari, M., Khodayari, M., Khaleghi, A., Danesh, M., & Padash, H. (2020). *Technological innovation research in the last six decades: a bibliometric analysis*.

Alfred, A. A., & Zawedde, B. M. (2022). *Factors Affecting Adoption of Improved Technologies For Sunflower Production in Madi Sub Region, Uganda:*

Alvar-Beltrán, J., Elbaroudi, I., Gialletti, A., Heureux, A., Neretin, L., & Soldan, R. (2021). *Climate resilient practices:Typology and guiding material for climate risk screening. Rome FAO*.

Andrianasolo, F. N., Debaeke, P., Champolivier, L., & Maury, P. (2016). *Analysis and modelling of the factors controlling seed oil concentration in sunflower: a review*.

ANZSRC. (2020). *Australian New Zealand Standard Research Codes and Categories*.

BoT. (2017). *Potentiality of Sunflower Sub-sector in Tanzania: Working Paper Series*.

Debaeke, P. P., Bret-Mestries, E., Aubertot, J.-N., Pierre, Casadebaig, Champolivier, L., Dejoux, J.-F., Maury, P., & Seassau, C. (2020). *Sunflower agronomy: 10 years of research in partnership within the "Sunflower" Technological Joint Unit (UMT) in Toulouse*.

DeLay, N. D., Thompson, N. M., & Mintert, J. R. (2022). Precision agriculture technology adoption and technical efficiency. *Journal of Agricultural Economics*, *73*(1), 195–219. https://doi.org/10.1111/1477-9552.12440

Dimitrijevic, A., & Horn, R. (2018). *Sunflower Hybrid Breeding: From Markers to Genomic Selection*.

EFECA. (2022). *Vegetable Oil Markets Briefing Note: The Impact of the Conflict in Ukraine*.

FAO. (2022). *Leveraging automation in agriculture for transforming agrifood systems. Rome, FAO.*

FAO & WPF. (2021). *Hunger Hotspots: FAO-WFP early warnings on acute food insecurity (March to July 2021 outlook) (also available at: https://www.wfp.org/publications/hunger-hotspotsfao-wfp-early-warnings-acute-food-insecurity-march-july-2021-outlook).*

FAOSTAT. (2021). *Production of Sunflower Seeds in Tanzania. https://www.faostat.org*.

Feng, L., Tang, H., Pu, T., Chen, G., Liang, B., Yang, W., & Wang, X. (2022). *A bibliometric analysis of 30 years of research publications*.

Fuglie, K., Gautam, M., Goyal, A., & Maloney, W. F. (2020). Harvesting Prosperity: Technology and Productivity Growth in Agriculture. In *Harvesting Prosperity: Technology and Productivity Growth in Agriculture* (Issue February 2021). https://doi.org/10.1596/978-1-4648-1393-1

GAIN. (2021). *Oilseeds and Products Update*.

Gaviglio, A., Filippini, R., Madau, F. A., Marescotti, M. E., & Demartini, E. (2021). Technical efficiency and productivity of farms: a periurban case study analysis. *Agricultural and Food Economics*, *9*(1). https://doi.org/10.1186/s40100-021-00181-9

HLPE. (2023). *Impacts of COVID-19 on food security and nutrition: developing effective policy responses to address the hunger and malnutrition pandemic*.

Inovia, T., & Brétignières, A. L. (2020a). *Sunflower in the global vegetable oil system: situation, specificities and perspectives*.

Inovia, T., & Brétignières, A. L. (2020b). Sunflower in the global vegetable oil system: Situation, specificities and perspectives. *E. Pilorgé: OCL*, *27*(34). https://doi.org/https://doi.org/10.1051/ocl/2020028

Isinika, A. C., & Jeckoniah, J. (2021). The political economy of sunflower in Tanzania: a case of Singida region. *Working Paper - Agricultural Policy Research in Africa (APRA)*, *49*, 33 pp. https://opendocs.ids.ac.uk/opendocs/bitstream/handle/20.500.12413/16459/APRA WP49_Political_Economy_of_Sunflower_in_Tanzania_A_Case_of_Singida_Region.pdf?sequence=1&isAllowed=y

Jayne, T. S., Fox, L., Fuglie, K., & Adesoji, A. (2021). Agricultural productivity growth, resilience, and economic transformation in Sub-Saharan Africa. In *United States Agency for International Development*. https://creativecommons.org/licenses/by/4.0.Thefullreportcanbeaccessedelectronicallyat:https://www.usaid.gov/bifad/

Jebur, H. A., AL-Halfi, K., Himoud, M. S., Yasin, S., & Jassim. (2024). *Sunflower Productivity Response to tillage Depth and Harrowing Speed*.

Joci´c, N., Müller, J., Požar, T., & Bertermann, D. (2020). *Renewable Energy Sources in a Post-Socialist Transitional Environment: The Influence of Social Geographic Factors on Potential Utilization of Very Shallow Geothermal Energy within Heating Systems in Small Serbian Town of Ub*.

Kamugisha, P. P., Leonard, A., & Mhanga, S. F. (2020). Investment Analysis of Sunflower Farming and Prospects of Raising Household income in Iramba District, Tanzania. *International Journal of Environment, Agriculture and Biotechnology*, *5*(4), 1062–1069. https://doi.org/10.22161/ijeab.54.27

Karunathilake, E. M. B. M., Le, A. T., Heo, S., Chung, Y. S., & AndSheikhMansoor. (2023). *The Path to Smart Farming: Innovations and Opportunities in Precision Agriculture*.

Kaya, Y., & Tan, A. S. (2029). *Sunflower (Helianthus annuus L.) genetic resources, production and researches in Turkey☆*.

Kingu, D. G., Msuya, C. P., & Kalungwizi, V. J. (2024). Institutional Factors Influencing Sunflower Productivity in Mkalama District. *European Journal of Agriculture and Food Sciences*, *6*(2), 26–32. https://doi.org/10.24018/ejfood.2024.6.2.764

Kombe, C., Mpemba, Z., Yabu, N., Kazi, M., Machemba, J., Kibesse, B., Mwita, D., Mgangaluma, E., Mashini, S., Chaula, A., Ndunguru, E., Lugobi, M., & Mziy, M. (2017). *Potentiality of Sunflower Sub-sector in Tanzania*.

Kumar, M., Malik, D. P., Singh, A., & Kumar, A. (2024). *Economic Analysis and Resource se Efficiency of Sunflower u Cultivation in Haryana*.

Liampawe, G. S. (2019). *Improving Productivity and Production of Sunflower Oilseeds among Smallholder Sunflower Farmers: A Value Chain Analysis Approach, A case study of Kalambo District, Tanzania:* Van Hall Larenstein University of Applied Science The Netherlands.

Lyanga, T. M. (2024). *Analysis of Costs of Inputs for Sunflower Production at Mkalama District in Tanzania*.

Masaki, C., & Marwa, N. (2019). *Increase in domestic demand of edible oil and potential opportunity of increasing unflower Seeds Production in Tanzania* (4).

Méndez-Zambrano, P. V., Pérez, L. P. T., Valdez, R. E. U., Flores, Á. P., & Orozco. (2023). *Technological Innovations for Agricultural Production from an Environmental Perspective: A Review*.

Mpenda, Z. . ., & & Mgen, C. . (2021). *Can Sub-Saharan Africa become Food Self-sufficient? Analyzing the Market Demand for Sunflower Edible Oil in Tanzania*. *20*(1), 42–53.

Mpenda, Z. . ., & Mgen, C. . (2021). Can Sub-Saharan Africa become food self-sufficient? Analyzing the market demand for sunflower edible oil in Tanzania. *Tanzania Journal of Agricultural Sciences, 20*(1), 42–53.

Mukherjee S, Padaria RN, B. R., Velayudhan PK, Mahra GS, Aditya K, S. S., Saini S, Mallick S, Quader SW, S. K., & AG, G. B. and B. (2025). *Global trends in ICT-based extension and advisory services in agriculture: a bibliometric analysis. Front. Sustain. Food Syst. 9:1430336. doi: 10.3389/fsufs.2025.1430336*.

Mussa, M. A. (2020). *Exploring Factors Affecting Agricultural Productivity in Tanzania: Policy Implication for Climate Chang*.

Mwangi, M., & Kariuki, S. (2015). Factors Determining Adoption of New Agricultural Technology by Smallholder Farmers in Developing Countries. *Issn*, *6*(5), 2222–1700. www.iiste.org

Mwatawala, H. W., Jeremiah, I., & Mwaseba, S. L. (2022). *Factors Influencing Technical Efficiency of Sunflower Production among Smallholder Farmers in Chemba District, Central Tanzania*.

Ngoma, H., Angelsen, A., Jayne, S., & Chapoto, A. (2021). *Understanding adoption and impacts of conservation agriculture in eastern and southern Africa: a review. Front. Agron. 3, 1–12. doi: 10.3389/fagro.2021.671690.*

NSA. (2012). *NSA funded research. https://www.sunflowernsa.com/Research/NSA-Funded-Research/2012-NSA-Funded-Research/*.

Pilorgé, E. (2020). *Sunflower in the global vegetable oil system: situation, specificities and perspectives. OCL, 27, 34.*

Presotto, A., Hernándeza, F., Díazb, M., Ivana, F.-M., Pandolfoa, C., Basualdoa, J., Cupparib, S., Cantamuttod, M., & Poveren, M. (2017). *Crop-wild sunflower hybridization can mediate weediness throughout growth-stress tolerance trade-offs*.

Puttha, R., Venkatachalam, K., Hanpakdeesakul, S., Wongsa, J., Parametthanuwat, T., Srean, P., Pakeechai, K., & Charoenphun, N. (2023). *Exploring the Potential of Sunflowers: Agronomy, Applications, and Opportunities within Bio-Circular-Green Economy*.

Sarwosri, A. W. (2020). *Analysing Smallholder Farmers' Adoption of New Technology Under the Consideration of Risk Attitudes and Time Preferences* (Issue March 1988).

Seiler, G., Qi, L., & Marek, L. (2017). *Utilization of sunflower crop wild relatives for cultivated sunflower improvement. Crop Science, 57(3):1083-1101.*

Shreya Kar, S., Anshuman, J., & Kundu, T. (2021). *Climate Resilient Agriculture and Sustainable Practices*.

Škorić, D. (2016). *Sunflower Breeding for Resistance to Abiotic and Biotic Stresses*.

Tandon, A., Dhir, A., Almugren, I., AlNemer, G. N., & M€antym€aki, M. (2021). *Fear of missing out (FoMO) among social media users: a systematic literature review, synthesis and framework for future research*.

Tibamanya, F. Y., Henningsen, A., & Milanzi, M. A. (2022). Drivers of and barriers to adoption of improved sunflower varieties amongst smallholder farmers in Singida, Tanzania: A double-hurdle approach. *Q Open*, *2*(1), 1–31. https://doi.org/10.1093/qopen/qoac008

Tibamanya, F. Y., Milanzi, M. A., & Henningsen, A. (2021). Drivers of and barriers to adoption of improved sunflower varieties amongst smallholder farmers in Singida, Tanzania: The double-hurdle approach, IFRO Working Paper, No. 2021/03, University of Copenhagen, Department of Food and Resource Economics (IFRO),. In *Oilseeds &fat crops and lipid* (Vol. 28, Issue 26).

USDA. (2022). *Ukraine Agricultural Production and Trade. U.S. Department of Agriculture, Foreign Agricultural Services. Available at: https://www.fas.usda.gov/sites/default/files/2022-07/Ukraine-Factsheet-July2022.pdf. Retrieved on 16/02/2023. July*, 1–2. https://apps.fas.usda.gov/psdonline/circulars/oilseeds.pdf

van Dijk, R., Godfroy, A., Nadeu, E., & Muro, M. (2024). *Increasing climate change resilience through sustainable agricultural practices: evidence for wheat, potatoes and olives', Research Report, Institute for European Environmental Policy*.

Vretenar, N. (2025). *TECHNOLOGY AND INNOVATIONS IN AGRICULTURE*.

Yu, D., Song, W., Wang, Q., Kang, Y., Lei, Y., Wang, Z., Chen, Y., Huai, D., Xin, W., Liao, B., & Yan, L. (2023). *Profiling and geographical distribution of seed oil content of sunflower in Ukraine*.

Zheng, Q., & Liu, K. (2022). *Worldwide rapeseed (Brassica napus L.) research: A bibliometric analysis during 2011–2021*.

Zozimo, T. M., Kawube, G., & Kalule, S. W. (2023). The role of development interventions in enhancing technical efficiency of sunflower producers. *Journal of Agriculture and Food Research*, *14*(November 2022), 100707. https://doi.org/10.1016/j.jafr.2023.100707

Zymaroieva, A., Zhukov, O., Fedoniuk, T., Pinkina, T., & Vlasiuk, V. (2021). Edaphoclimatic factors determining sunflower yields spatiotemporal dynamics in northern Ukraine. *OCL - Oilseeds and Fats, Crops and Lipids*, *28*. https://doi.org/10.1051/ocl/2021013