Analysis of Technology Dissemination in Crop Production: Mapping Research Trends using Scopus

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Abstract**—** *The existing global framework of research on agricultural technology dissemination in crop production is still multidisciplinary and has not been integrated. This study conducts a comprehensive bibliometric analysis on 346 documents indexed in Scopus from 1986 to 2025 in order to map the evolution, structure, and emerging frontiers of scholarly work on agricultural technology diffusion. Moreover, this work utilized statistical methods and network mapping in R software to analyze growth trajectories as well as identify key authors, institutions, countries, and their collaboration patterns. Although India documented the most output (13.3% of documents), it had very few international partnerships. Conversely, Kenya achieved the highest average citation impact through extensive cross-border collaboration despite having fewer articles. Also, ICRISAT, Tamil Nadu Agricultural University, and ICAR-IARI, which are all in the region and serve as centers of agri-innovation, stood out as leading institutions. From the co-occurrence of keywords, some broad agronomic topics have been shifted toward more advanced concepts such as sustainability, climate resilience, and precision agriculture, which helps to reflect the global food security agenda. Longitudinal analyses point out an inflection point (turning point) around the year 2008, after which the terms "food security", "climate change", and "precision farming" started to emerge more frequently. Although there is rapid growth at a rate of 7.4% per year, it is evident that there is stagnant growth due to a lack of critical infrastructure, limited access to credit, poor extension services, and largely unexplored mechanisms for marketing, financing, and adoption on a large scale. This study creates an evidence-based roadmap by mapping the gaps in the field's intellectual structure and highlighting under-researched areas. This roadmap can be utilised by researchers, policymakers, and extension agents to streamline future investigations, collaborations, and devise strategic interventions that expedite the global dissemination of transformative technologies to farmers.*

Keywords— Technology dissemination, Crop production, Agricultural technology, Research trends, Bibliometric analysis. Scopus database.

I. INTRODUCTION

The relentless momentum of global population expansion, expected to reach nearly 10 billion by 2050, meets the rising provocations of climate change, confronting global food security with its greatest challenge yet (Hulme, 2023). Crop production, as the base and source of human sustenance, is also the area most directly impacted (Wang, 2022). Raising yields, improving tolerance against biotic and abiotic stress conditions, and achieving optimal resource use efficiency are no longer options but a must (González Guzmán et al., 2022). In this critical environment, agri-tech —encompassing technologies such as precision farming, sensor networks, advanced biotechnology, robotics, artificial intelligence, and data analytics —serves as a driving force with the power to transform (Ashique et al., 2024). They represent significant productivity gains to feeding an expanding population while reducing the environmental footprint of agriculture (Holka et al., 2022). However, it is not enough for sophisticated agricultural technologies to exist. The challenge of transferring technology from research benches or pilot farms to mass and practical application by farmers across a wide range of crop production systems worldwide is a significant and intricate bottleneck. This technology transformation process, commonly referred to as technology transfer, includes the complex interrelations of communication media, extension services, socio-economic determinants, policy, infrastructure, farmer knowledge, and costs and benefits (Becerra-Encinales et al., 2024). However, when the gap isn't bridged in a meaningful way, the most promising examples of innovation collapse on themselves, and progress toward feeding people and engaging in

sustainable agricultural practices doesn't materialise. Characterising the dynamics, determinants, and constraints of dissemination innovation in crop production is, therefore, not simply an academic exercise but a basic necessity for translating scientific potential into reality on-farm and achieving global value (Bull et al., 2024). Despite this, the spread of technology in the crop production domain is a diffuse and fragmented research space. Although various case studies, regional investigations, and technology-specific use cases exist, constructing a comprehensive global view of research trends, knowledge evolution, and intellectual aspects of a diverse area such as this has been quite challenging.

Questions persist: How has scholarly focus on dissemination mechanisms evolved? Which specific technological domains (e.g., digital agriculture, genomics, sustainable practices) dominate dissemination research? What are the predominant methodological approaches? Where are the geographic concentrations of research activity, and where are the concerning gaps? Which institutions and authors are shaping the discourse?

Identifying the core themes, emerging frontiers, and potential knowledge silos is essential for guiding future research priorities, optimizing funding allocation, informing policy interventions, and ultimately accelerating the flow of beneficial technologies to the farmers who need them. Bibliometric analysis offers a powerful, quantitative lens through which to map and analyze the vast corpus of scholarly literature systematically. By employing statistical methods to examine publication patterns, citation networks, keyword co-occurrence, and author/institutional collaborations, bibliometrics can reveal hidden structures, trace the evolution of ideas, identify influential works and actors, and visualize the conceptual landscape of a research field. The Scopus database, renowned for its extensive multidisciplinary coverage, rigorous curation, and comprehensive citation indexing, provides an ideal dataset for such an endeavor. Its broad scope encompasses research output across diverse geographical regions and disciplines relevant to agricultural technology dissemination, including agronomy, agricultural economics, information technology, and social sciences.

This article, therefore, undertakes a comprehensive bibliometric analysis to map and elucidate the research trends in technology dissemination within crop production, utilizing the rich metadata available through the Scopus database. We aim to move beyond isolated studies to provide a macroscopic, evidence-based overview of the field's development over time. Specifically, our analysis seeks to: (1) Quantify the growth trajectory and publication volume of research in this domain; (2) Identify the most prolific countries, institutions, and authors driving the discourse; (3) Discern the predominant research themes and their evolution through keyword and term co-occurrence analysis; (4) Highlight seminal works and journals that have significantly influenced the field; and (5) Uncover emerging trends and potential future research directions. By synthesizing these diverse dimensions, this study provides an invaluable map of the intellectual territory surrounding the dissemination of technology in crop production.

The generated insights should be helpful in multiple groups: researchers can locate understudied niches and potential collaborators; policymakers and funders can more accurately decide how to proceed based on the positive and negative trends found in the evidence; extension and technology transfer agents can improve how they think about their research dissemination possibilities; and agricultural educators can bring curricula on par with the dynamic knowledge base. Finally, through revealing the structure and dynamics of research in this key interstitial space, this analysis adds to the vitally needed development of a more secure understanding of knowledge dynamics – and thus a more effective evidence base for intervention design – to secure that agricultural innovation can reach and benefit farmers worldwide, ensuring that our global food systems become and remain more resilient and productive under the weight of growing challenges. This research may not be merely a literature search; it should serve as a stepping stone toward marketing the laboratory to the field on the same path of development.

1.1 Technology Dissemination in Crop Production:

To boost global food security in the face of population growth, climate variability, and resource limitations, the use of high-tech agriculture (AgTech) is required (Anim et al., 2025). Innovations, including stress-tolerant seeds, precision nutrient systems, remote sensing, IoT, AI, and robotic systems, have the potential to be transformative for crop cultivation by yielding more, using fewer resources, and reducing harmful environmental impact (Pehlivan et al., 2025). However, just because these technologies exist doesn't mean they will have a broad influence. Translating from novelty to scalable, practical application is dependent on the complex, piecemeal undertaking of technology diffusion.

This is about more than shallow 'transfers.' It is a complex, evolving function of social-technical navigation through the creation, sharing, spread, adoption, modification, and persistence of new ideas and practices in specific farming systems and socio-economic circumstances (Giagnocavo et al., 2022). It probes the entire pathway – the actors, channels, and influences involved in how knowledge is created, shared, understood, validated, trialled, adapted, and adopted by farmers. The movement

of knowledge is conducive to learning and helps to effect change in complex systems with numerous stakeholders, limited resources, diverse environmental contexts, and entrenched cultural beliefs (Eaton et al., 2021). Its significance is paramount. Innovations that fail to reach farmers are wasted investments—and lost opportunities to address soil degradation, water stress, climate-related pests, and the fragility of smallholder farming. The enduring 'knowing-doing gap' remains a significant barrier to achieving global food security and sustainability (Santos, 2025). Information diffusion is a fundamental aspect of agricultural development, directly affecting the extent of the return on investment in R&D, as well as the sector's ability to adapt at speed.

Diffusion occurs in complex ecosystems. Innovators and Researchers generate knowledge. Information flow is typically managed by Extension Services (public, private, or NGO). Input Farmers or input suppliers begin to sell technology directly. Farmers are assessing creatures, evaluating innovations based on their relevance, advantage, complexity, compatibility, trialability, and observability, according to Rogers' Diffusion of Innovations paradigm (Dissanayake et al., 2022). Policymakers create the environment through subsidies, regulation, and infrastructure. Media ICTs, Financial Institutions, and Farmer Groups also have key roles to perform.

The process comprises stages such as awareness, knowledge, persuasion, decision, implementation, and confirmation. Farmers often modify technologies to suit local contexts, thereby increasing their applicability. Diffusion is heavily context-dependent, influenced by policy, markets, physical infrastructure (such as roads and connectivity), agroecology, socio-cultural factors (including gender and networks), and farmer economics and risk aversion. The typical constraints include a lack of financial resources, limited access to credit, knowledge gaps, inadequate infrastructure, perceived complexity about skills and resources, relevance and information asymmetry, and weak extension and policy. Technology dissemination is the ultimate driver that converts the potential of agricultural innovation into the actual impact on productivity, sustainability, and livelihoods. It requires evolved knowledge and strategized action for what is groundbreaking AgTech to become realized. Our secondary task is to chart how research interacts with this critical literature.

II. LITERATURE REVIEW

2.1 Technology Dissemination in Crop Production – Insights from Empirical Research:

The sharing of farm technology is a sociotechnical process that is crucial for transforming research-based innovations into on-farm benefits, which can contribute to the improvement of rural livelihoods, especially in developing country contexts where environmental and resource constraints are often severe. Moreover, research about Bangladesh, in particular, published (or indexed) as shown by Scopus itself in the academic literature, provides insightful and empirical understanding concerning the process, issues, and effects of spreading technology through crop production systems. Together, these studies highlight several key motifs that are crucial to understanding dissemination routes. One conclusion that emerges from several studies is the key role played by participatory methods and farmer involvement. The adoption of on-farm water management technologies could be increased, as reported by Zaman and Patra (2012), if the farmers were involved in research at all levels. Participatory action research fostered trust, promoted adoption on a cost-benefit basis, and proved cost-effective in developing location-specific answers. Similarly, Bairagi et al. (2021) reported that access to information on flood-tolerant rice from neighbours and farmer organizations, as well as training, were the major drivers of adoption, highlighting the importance of social networks and peer-based learning through organized groups. This finding is consistent with the observations of Farouque and Takeya (2017), who noted that extension workers identified farmer training and frequent visits as the most effective means of disseminating ISFM technologies, highlighting the interpersonal aspect of knowledge transfer.

Additionally, the importance of tailoring and adapting technology to local agro-ecological and socio-economic realities is emphasized in the literature. Kabir et al. (2017) observed how coastal Bangladeshi farmers, affected by salinity intrusion and climate variability, had developed a range of adaptation mechanisms, including changing sowing times, adopting salinity-tolerant crop varieties, and altering field structures (e.g., digging ditches). It was not a passive adoption; this was an active reinvention, an idea at the core of Rogers' Diffusion of Innovations theory, which was implicitly reflected in studies like those by Wahab et al. (2011) in polyculture systems. The success of transfer depends on the transferability of technology, i.e., the degree to which technology aligns with, among other things, local characteristics like soil, water, cropping patterns and cultural practices, as emphasized by Hossen (2019) in the choice of suitable agricultural machinery across the wide-ranging agro-ecological sub-regions of Bangladesh. Bairagi et al. (2021) further supported our conclusion, as they demonstrated that the

impacts of Sub1 rice adoption on yield, profit, and consumption varied across locations, indicating that dissemination must be area-specific.

The study also highlights the existence of systemic barriers to the widespread adoption of technology. Infrastructure constraints, including inadequate irrigation, drainage, and rural roads, electricity, and digital connectivity for modern mechanization, as well as information accessibility, are often mentioned as constraints. Economic barriers, such as high entry costs for machinery, limited access to credit, and perceived investment risks, are significant barriers to adoption for particularly resource-poor smallholders. Knowledge shortfalls, together with weak extension linkages, still constitute a challenge. However, an overall positive attitude towards integrated soil management was reported in a study by Farouque and Takeya (2017), indicating the need for increased in-service training and access to research centres. Kabir et al. (2017) and Bairagi et al. (2021) also found that a lack of access to extension services and technical knowledge and skills hindered the uptake of adaptation practices and new varieties. Market-related and availability of inputs for new technologies and crops are identified as essential variables contributing to sustaining adoption.

Lastly, the literature highlights that successful dissemination has the potential to impact agricultural resilience, productivity, and livelihoods significantly. Flood-tolerant Sub1 rice adoption had significant positive effects on crop yield (6%), net benefits (55%), and annual household rice intake (15%) in flood-prone northwest Bangladesh. Likewise, strategic species manipulation in rice-fish polyculture systems, and enhanced water management procedures have yielded realizable gains in yield and income. The pace of context for this policy brief is high, emphasizing the need for mechanization to enhance labour productivity and operational timeliness, reduce post-harvest losses, increase cropping intensity, and, consequently, enhance overall output. Other studies also show that well-diffused technology can improve climate resilience, enabling farmers to address environmental stresses such as flood, salinity, and drought and, as such, could offer a significant contribution to achieving food security objectives. Finally, the empirical evidence from Bangladesh confirms that successful technology uptake in crop agriculture is not a one-way transfer but rather a context-specific process which requires participatory technology development, adaptation to realities at the farm level, joint efforts to overcome the systemic barriers, and strong linkages along the knowledge continuum among research, extension, input suppliers, policymakers and farmers to realize its full potential for sustainable agriculture.

III. METHODOLOGY

This study employs comprehensive scientific mapping techniques to conduct a bibliometric analysis of "Technology Dissemination in Crop Production" using the Scopus database. The analysis spans from its first publication in 1986 to 2025. Scopus, a widely recognized source of bibliographic information, provides a reliable foundation for this research.

3.1 Data Collection:

The initial data collection was conducted using the keywords **Technology Dissemination AND Crop Production** within the Scopus database, resulting in 346 publications, as identified by the Article Title, Keywords, and Abstract to ensure the inclusion of contemporary and relevant research. Each publication's complete record, including references, was exported for bibliometric analysis. The search was finalized on July 1, 2025.

3.2 Literature Review:

The 6 articles were subject to a comprehensive full-text evaluation to ascertain their relevance, quality, and contribution to TDCP research in Bangladesh. The data collection was conducted using the keywords **Technology Dissemination AND Crop Production AND Bangladesh** within the Article Title, Keywords, and Abstract**.** The systematic literature review was designed to extract significant topics, methodologies, and conclusions, comprehensively examining current research. This method assisted in identifying gaps in previous research and establishing a connection between the bibliometric data and relevant insights.

3.3 Analytical Tools:

The bibliometric analysis was conducted using the R programming language and the strong scientific mapping and analysis tool from the Bibliometric package (Uddin et al., 2025). Data handling and visualization were facilitated using R Studio and Excel (Mahedi et al., 2025; Md Shahriar Kabir et al., 2025).

This systematic methodology facilitates a comprehensive investigation of the evolution and dynamics of research on technology dissemination in crop production, offering vital information for future research and policy-making in this area. The research process followed in this paper is illustrated in Figure 1.

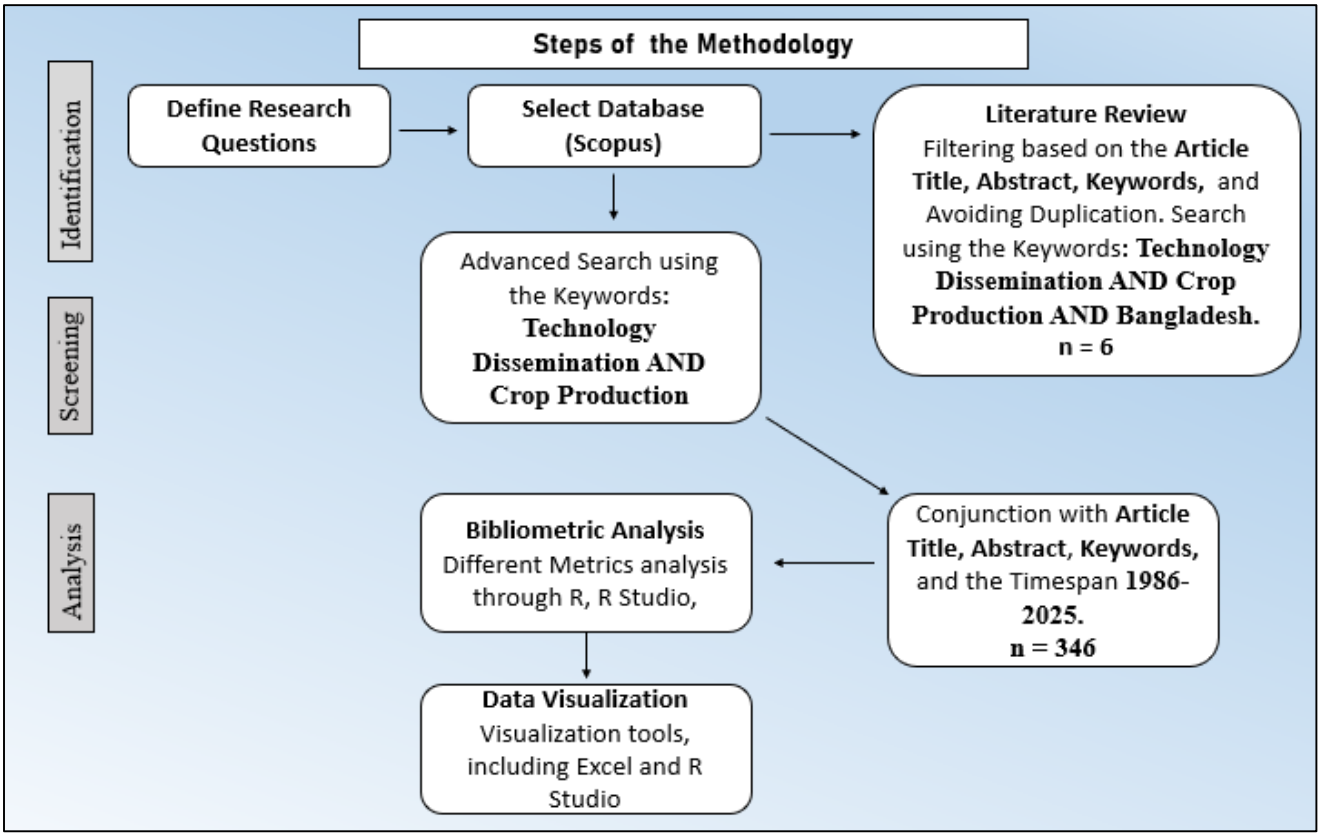

FIGURE 1: The steps in research methodologies.

Source: Original material of the study

IV. RESULT AND ANALYSIS

4.1 Primary data-related information:

The dataset utilized in this study, as summarized in **Table 1**, provides a comprehensive overview of the scholarly literature on technology dissemination in crop production, extracted from Scopus. The analysis spans four decades (1986–2025), encompassing 346 documents published across 235 diverse sources, including journals, books, and conference proceedings. The field exhibits a robust annual growth rate of 7.37%, reflecting increasing academic and practical interest in agricultural technology diffusion. The documents, with an average age of 8.86 years, demonstrate sustained relevance, further evidenced by a substantial average citation count of 24.49 per document, indicating strong scholarly impact. A total of 16,337 references were analyzed, highlighting the depth of interconnected research in this domain.

The dataset includes 1,634 Keywords Plus (ID) and 1,256 Author's Keywords (DE), illustrating the conceptual breadth of the field. Contributions come from 1,416 authors, with a limited proportion (42 single-authored documents) suggesting a highly collaborative research landscape. The average of 4.37 co-authors per document and a 32.37% international co-authorship rate underscore the global and interdisciplinary nature of agricultural technology research. Document types include 37 book chapters, 45 conference papers, and 1 conference review, reflecting varied dissemination channels. This structured dataset provides a robust foundation for bibliometric mapping and trend analysis, enabling insights into the evolution and future directions of technology adoption in crop production.

TABLE 1
THE PRIMARY INFORMATION ABOUT THE DATA UTILIZED IN THE STUDY.

Description	Results
Timespan	1986:2025
Sources (Journals, Books, etc.)	235
Documents	346
Annual Growth Rate %	7.37
Document Average Age	8.86
Average citations per doc	24.49
References	16337
Keywords Plus (ID)	1634
Author's Keywords (DE)	1256
Authors	1416
Authors of single-authored docs	42
Single-authored docs	42
Co-Authors per Doc	4.37
International co-authorships %	32.37
book chapter	37
conference paper	45
conference review	1

4.2 Author's Outputs:

Figure 2 presents a rigorous quantitative assessment of scholarly contributions to technology dissemination in crop production, revealing insightful patterns in author productivity. The analysis identifies five principal investigators who have made substantial contributions to the field, with Kumar A, Sharma A, and Singh S each having five publications, while Akinnifesi FK and Chianu JN follow closely with four publications each. Notably, the fractionalized article count, which accounts for proportional authorship in collaborative works, reveals distinct patterns of research engagement. Sharma A and Singh S demonstrate particularly strong collaborative contributions with fractionalized scores of 1.45 and 1.43, respectively, suggesting their consistent involvement as significant contributors across multiple studies. In contrast, Kumar A's fractionalized score of 0.85 indicates a different pattern of co-authorship engagement. The data underscores the critical role of these researchers in advancing the field while highlighting varying collaboration patterns among leading contributors. This analysis provides valuable insights into the research landscape, demonstrating both the concentration of scholarly output among key authors and the nature of collaborative networks in agricultural technology dissemination research.

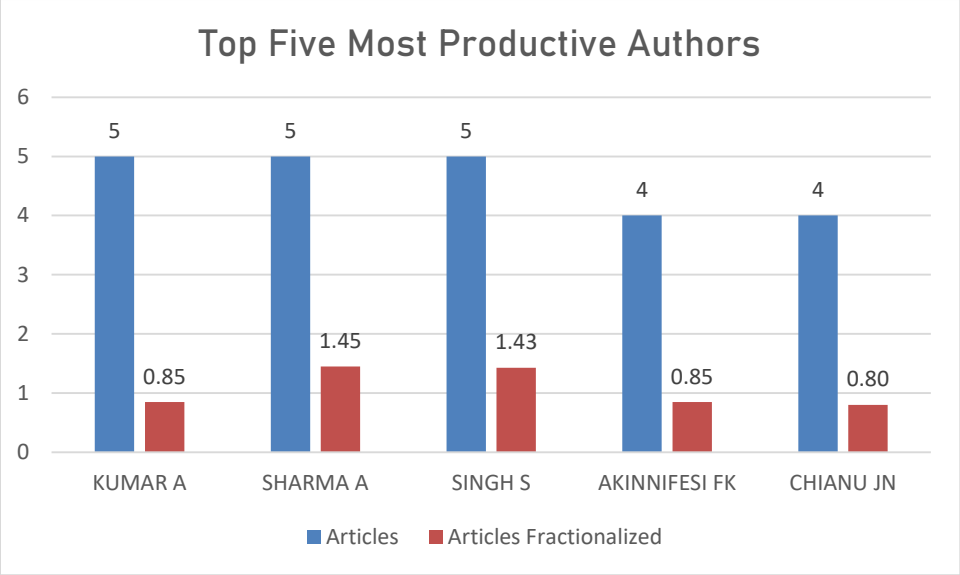

FIGURE 2: Analysis of Author Productivity in Technology Dissemination Research.

4.3 Active Institutions:

This analysis of institutional affiliations reveals a distinct geographic and organizational concentration of research output in agricultural technology dissemination. As illustrated in Figure 3, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) emerges as the most prolific contributor with 18 articles, reflecting its global leadership in semi-arid agricultural innovation. Closely following are Tamil Nadu Agricultural University (16 articles) and ICAR-Indian Agricultural Research Institute (14 articles), demonstrating India's strong research capacity in this domain. The presence of Huazhong Agricultural University (12 articles) highlights China's growing influence, while the International Centre of Insect Physiology and Ecology (ICIPE) equally contributes 12 articles, emphasizing Africa's role in addressing unique agricultural challenges through technological solutions.

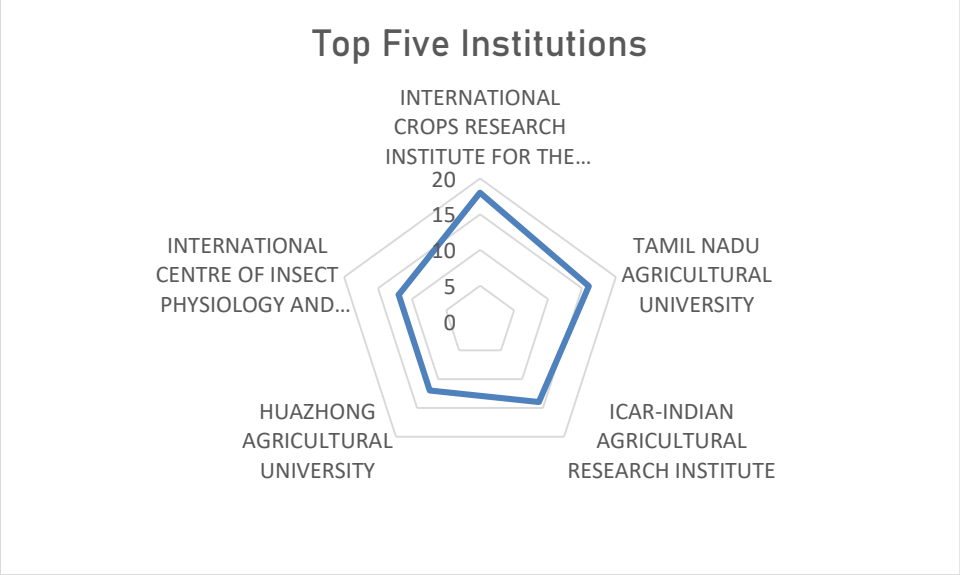

FIGURE 3. Institutional Contributions to Technology Dissemination Research in Crop Production.

4.4 Corresponding Authors' Countries:

The analysis of country-level contributions reveals distinct patterns of research productivity and international collaboration in agricultural technology dissemination. As depicted in Figure 4, the dataset comprises 100 articles, with India emerging as the dominant contributor (46 articles), accounting for nearly half of the total output. This is followed by Kenya (22 articles), China (21 articles), the United States (17 articles), and Ethiopia (12 articles), demonstrating a strong representation from both emerging and developed agricultural economies.

The data reveals particularly interesting collaboration dynamics through the Single Country Publications (SCP) and Multiple Country Publications (MCP) metrics. While India shows the highest absolute research output, its MCP ratio (0.13) indicates relatively limited international collaboration compared to Kenya, which demonstrates the most robust international engagement with an MCP ratio of 0.682 (15 of 22 articles involving international partners). The United States shows moderate collaboration (MCP ratio 0.294), while China and Ethiopia present intermediate profiles with MCP ratios of 0.19 and 0.333, respectively.

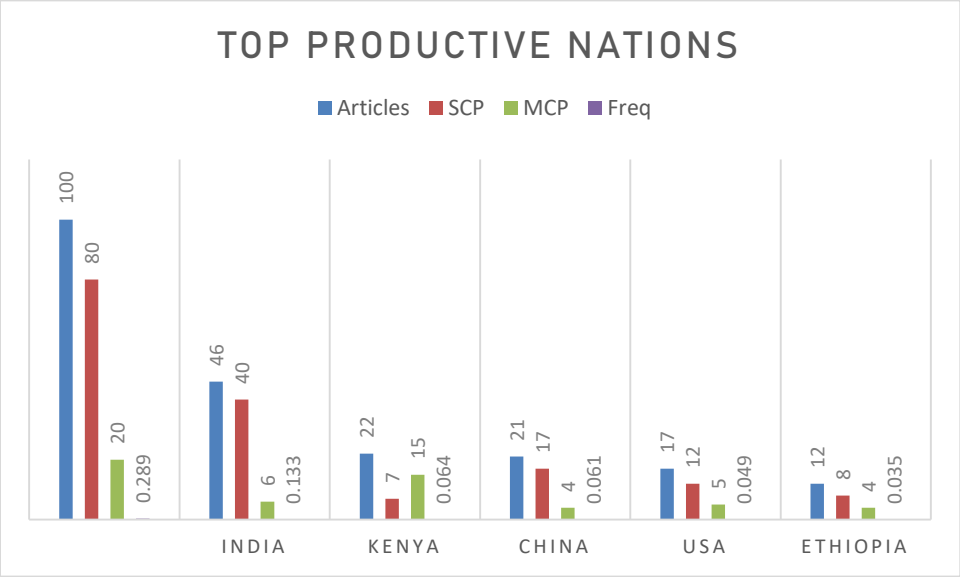

FIGURE 4: Geographic Distribution and Collaboration Patterns in Crop Technology Dissemination Research.

Table 2 presents a dual-faceted analysis of country-level contributions to technology dissemination research in crop production (TDCC), evaluating both research productivity and scholarly impact. The left panel ranks nations by publication volume, with India emerging as the dominant contributor (46 articles), accounting for 13.3% of the total output, followed by Kenya (22 articles), China (21 articles), the United States (17 articles), and Ethiopia (12 articles). Notably, India's research output is predominantly domestic, with 40 single-country publications (SCP) versus just 6 multi-country collaborations (MCP), reflecting a relatively insular research ecosystem. In contrast, Kenya demonstrates remarkable international engagement, with 15 of its 22 publications (68.2% MCP ratio) involving cross-border collaborations—the highest among all nations.

The right panel reveals a striking divergence between productivity and citation impact. While India leads in publication volume, it ranks fourth in total citations (TC = 399) and exhibits the lowest average citations per article (8.7) among the top five nations. Conversely, Kenya claims the highest total citations (979) despite its smaller publication output, with an impressive average of 44.5 citations per article, indicating the high influence of its internationally collaborative research. Similarly, Australia and Germany, though not among the top five most productive nations, achieve exceptional citation metrics (109.8 and 76.8 average citations, respectively), underscoring the outsized impact of their contributions. China maintains a balanced profile, ranking third in both productivity and citations (TC = 629; 30.0 average citations).

TABLE 2

THE TOP MOST PRODUCTIVE NATIONS BY CORRESPONDING AUTHORS IN THE TDCC DOCUMENTS INDEXED IN SCOPUS.

Productivity According to Number of Articles Published						Productivity According to the Number of Citations Per Country			
Rank	**Country**	**Articles**	**SCP**	**MCP**	**Freq%**	**Rank**	**Country**	**TC**	**Average Article Citations**
1	INDIA	46	40	6	0.133	1	KENYA	979	44.50
2	KENYA	22	7	15	0.064	2	CHINA	629	30.00
3	CHINA	21	17	4	0.061	3	AUSTRALIA	439	109.80
4	USA	17	12	5	0.049	4	INDIA	399	8.70
5	ETHIOPIA	12	8	4	0.035	5	GERMANY	384	76.80

4.5 Word cloud:

Figure 5 presents a keyword co-occurrence network analysis that reveals the conceptual landscape of technology dissemination research in crop production. The visualization identifies several interconnected thematic clusters that collectively demonstrate the field's multidimensional nature. Central to the network are the dominant nodes of "sustainable development" and "agricultural production", which serve as foundational concepts linking various research directions. These core themes connect strongly to three primary research streams: agroecological systems ("farming system", "climate change", "water management"), productivity enhancement ("crop yield", "food security"), and socio-technical dimensions ("technology adoption", "decision making", "participatory approach"). The network further reveals specialized clusters focusing on precision agriculture ("remote sensing", "irrigation"), innovation systems ("technology transfer", "innovation"), and socioeconomic aspects ("economics", "agricultural worker"), demonstrating the field's interdisciplinary character. Notably, the strong representation of sustainability-related terms underscores the increasing alignment of agricultural technology research with global sustainable development goals. The coexistence of traditional agronomic terms ("crop production") with emerging technological concepts ("information dissemination") illustrates the field's dynamic evolution. At the same time, relatively sparse connections in areas like animal agriculture may indicate potential research gaps. This analysis not only maps the current intellectual structure of the field but also provides valuable insights into knowledge diffusion patterns and potential future research trajectories in crop technology dissemination. The visualization's node-link relationships, where thicker connections represent stronger conceptual ties, offer empirical evidence of how different research themes interact and coalesce within this rapidly evolving domain.

FIGURE 5: Word cloud showing the top often-used authors in TDCC indexed in Scopus (1986–2025).

4.6 Words' Frequency over Time:

Figure 6 presents a longitudinal analysis of keyword frequency within the Scopus database, mapping the evolving research focus on technology dissemination in crop production from 1988 to 2025. The figure reveals a distinct pattern of thematic emergence and intensification. For the initial period (1988-2001), research activity was minimal, with only 'AGRICULTURE' and 'AGRICULTURAL TECHNOLOGY' registering sporadic, low-level occurrences. A subtle shift began around 2002, marked by the first appearances of 'RICE', 'CROP YIELD', 'CLIMATE CHANGE', and notably *'ZEA MAYS'* (maize), alongside increased counts for 'CROP PRODUCTION'. A significant acceleration commenced around 2007-2008, characterized by a steep upward trajectory across nearly all terms. This period saw 'CROP PRODUCTION' solidify its position as the dominant keyword, followed closely by 'AGRICULTURE'. Keywords like 'CROPS', 'CULTIVATION', 'RICE', 'CROP YIELD', 'FOOD SECURITY', and 'CLIMATE CHANGE' demonstrated substantial and sustained growth from this inflection point onwards. By the most recent data (2020-2025), the research landscape reflects a broad convergence of interconnected themes. 'CROP PRODUCTION' maintains the highest frequency, but terms like 'AGRICULTURE', 'CROPS', 'CULTIVATION', 'FOOD SECURITY', and 'CLIMATE CHANGE' show robust and increasing engagement, indicating the maturation of research integrating technological dissemination with broader agricultural systems, productivity goals, environmental pressures, and food security outcomes.

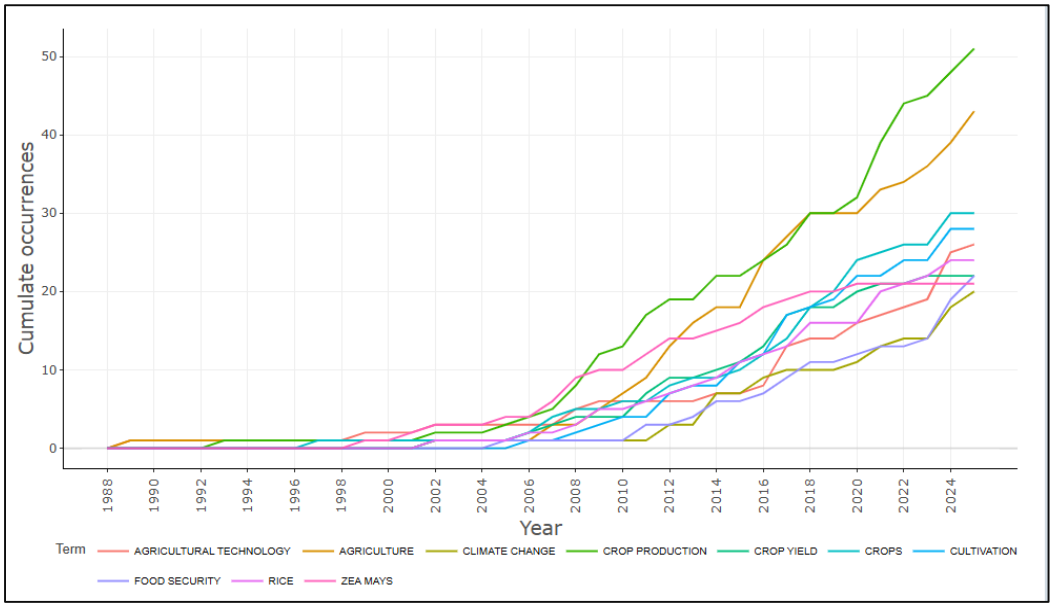

FIGURE 6: Word Frequency over Time

4.7 Co-occurrence Network:

Figure 7 presents a co-occurrence network analysis of keywords derived from the Scopus dataset, visually mapping the conceptual structure and thematic interconnections within research on technology dissemination in crop production. The network reveals a complex ecosystem centered on the core theme of 'crop production', which acts as a major hub. This hub directly connects to critical global challenges like 'food security' and specific crops such as 'maize', alongside key productivity drivers including 'crop yield', 'agricultural technology', and 'innovation technology adoption'. Practical implementation themes branch strongly from the core, encompassing 'irrigation', 'farming systems', and 'farmers' knowledge', emphasizing the human and applied dimensions of dissemination. The broader conceptual foundation is anchored by the overarching cluster 'econostics', linking 'sustainable development' with fundamental elements like 'human', 'crops', 'agriculture', and 'cultivation'. Bridging the theoretical and practical spheres is the cluster 'information dissemination productivity', featuring terms like 'social management', 'farming system', and 'soft fertility', highlighting the processes and systems enabling knowledge flow. The network underscores the integration of sustainability concerns ('sustainable development', 'strainability'), stakeholder engagement ('strainholder'), and socio-technical approaches ('protolydroxy approach', 'social management') within the field, demonstrating that research on disseminating agricultural technology is fundamentally interdisciplinary, connecting ecological, technological, economic, and social systems focused on enhancing production and security outcomes.

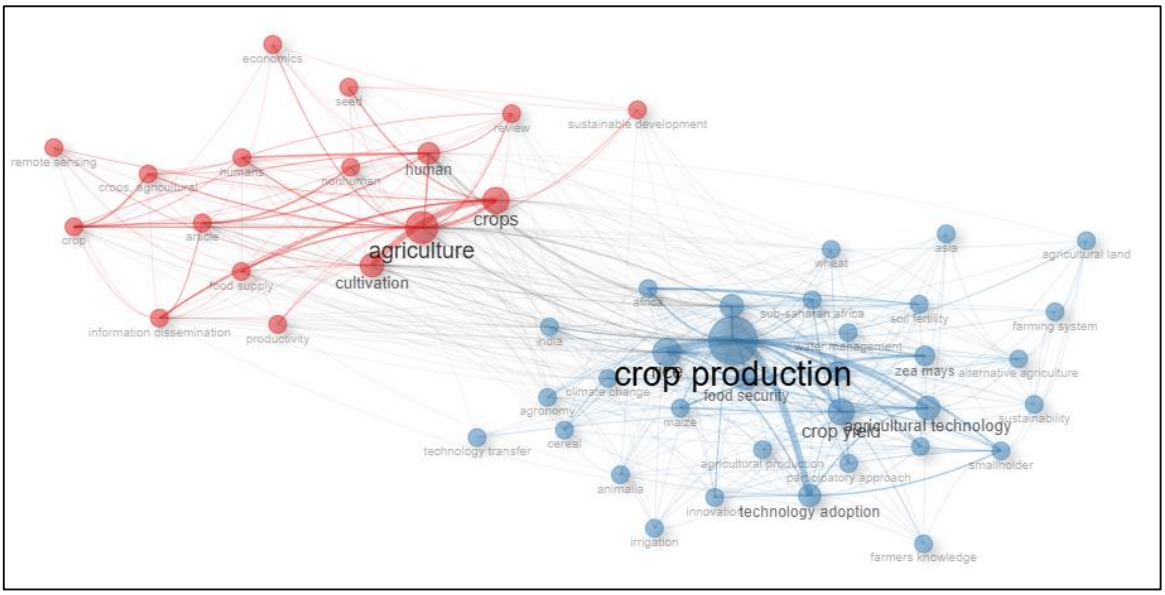

FIGURE 7: Co-occurrence network of the keywords.

V. DISCUSSION

This research in this study provides a bird's-eye view of the trends and dynamics of TDCP research. The issue of technological innovations in crop production is even more critical when set against the current global agricultural landscape, which is facing numerous challenges, including climate change, resource depletion, and increasing food insecurity. The trends presented in the current study also indicate an acceleration in research, as evidenced by the high growth rate of 7.37% for the annual publication rate over just two decades. This increase not only reflects growing interest in academia but also an increasing awareness that the dissemination of technology is a central element in achieving sustainable agricultural results.

India is also found to be the primary contributor to the TDCP research, having contributed a significant number of publications from prominent agricultural institutes, such as ICRISAT, Tamil Nadu Agricultural University, and ICAR-IARI. The overview of the research landscape reveals relative isolationism in India and a lack of global participation. This is in contrast to countries such as Kenya, which, despite a smaller overall publication output, shows an outstanding level of international involvement. The high visibility of Kenya internationally, along with high-value citation indicators, underscores the importance of global collaboration in enhancing the visibility of research. Notably, this contribution has significantly improved the academic impact of Kenya's research, providing further support for the need for international collaboration to address local research constraints and promote the broader adoption of technological solutions. One more key observation is the development of research themes in TDCP. Previous works have primarily focused on generic agri-food challenges; however, recent emerging approaches have demonstrated a significant shift toward addressing systemic global problems, such as climate change, food security, and sustainability. This shift in focus is reflected in the empirical evidence, where results from Bangladesh have demonstrated that technological innovations in flood-tolerant rice and climate-resilient cropping systems. Can lead to measurable increases in agricultural production and the resilience of farmers. Such technologies, which positively contribute to crop yield and profitability, are a clear manifestation of the practicality of technology when adequately applied. Furthermore, the growing alignment of research objectives with sustainability goals suggests that the field is evolving to address the interdependency of agricultural productivity, environmental sustainability, and socioeconomic variables. The convergence of diverse fields, such as agroecology and information technology, has also been gaining prominence in discussions about technology diffusion and demonstrates the interdisciplinarity of contemporary agricultural research.

The persistent lack of infrastructure and limited access to credit and extension services, particularly in resource-poor settings, continues to be a significant hindrance to the popularisation of these technologies. These systemic barriers persist despite the demonstrated potential for scaling agricultural innovations. For example, participatory trials and farmer-centric approaches have been successful in addressing some of the obstacles to adopting this kind of technology; however, such technologies cannot address system-wide categories of behavioural interventions on a localised level. Inadequate infrastructure, including insufficient irrigation facilities, poor digital connectivity, and a limited rural road network, continues to be a significant constraint in the effective transfer of agricultural technologies. Besides, the high capital investment in machinery and overall input programs poses a difficulty for smallholder farmers, such as those in developing countries, to access and accommodate high-technology packages. These obstacles are frequently further exacerbated by ineffective financial instruments that prevent farmers from making investments in technological innovations. Notably, the literature lacks sufficient information on the market access and financial mechanisms required to overcome these barriers. This identifies an apparent lacuna in the existing literature and suggests a need for future work to be directed towards policy-oriented solutions which tackle these socioeconomic drivers of technology acceptance." Moreover, a non-dedicated, integrated technology delivery system is highlighted by the underrepresentation of key themes in the bibliometric analysis of technology, including market access, financing, and extension. The structural challenges in society regarding the efficient dissemination of technology still deserve more attention, even though the field is booming in terms of volume and international cooperation. The study's findings indicate that further research is necessary to develop an integrated model for the transfer of agricultural technologies. This model should not focus solely on technological development but also encompass the essential infrastructural, financial, and institutional support required for adoption at scale.

The study also underscores the value of participatory methods and farmer involvement in technology transfer. Bangladesh case studies, particularly in the areas of water management and flood-tolerant rice, demonstrate that technologies are most effective when tailored to regional circumstances and when farmers are actively involved in their development and application. These participatory schemes enrich the technology's relevance and effectiveness, build trust, and thereby increase the likelihood of adoption. By engaging farmers at all levels of the technology adoption process, we can develop solutions tailored to local challenges, leading to both improved short-term service provision and longer-term benefits from successful technology introduction.

In the finale, although the domain of technology transfer in crop production is rapidly expanding and adapting to meet current challenges, numerous challenges remain, both in the literature and in practice. The current and ongoing success of technology diffusion initiatives is predicated not solely on innovation but also on the strategic removal of adoption barriers. This includes multidisciplinary development across technology, socioeconomics, and infrastructure, along with international linkage and participatory research. By identifying and addressing these gaps, future research can facilitate the transition from technological innovation to field-scale and policy impact, thereby ensuring that agricultural technologies fulfil their promise to enhance food security, sustainability, and farmer livelihoods worldwide.

TABLE 3
RELEVANT PAPER IN TDCC STUDIES

Authors	Paper Title	Approach	Problem Definition	Key Challenges	Key Results
Zaman & Patra (2012)	Water management technologies to increase crop and income per drop.	On-farm participatory action research with ICAR collaboration.	Inefficient water use in Flood/submergence-prone lowlands; low productivity after pre-kharif crops.	Poor drainage, flash floods, submergence, and irrigation-water gap.	Water management tech increased crop productivity (↑yield), income (↑55%), employment, and effectiveness through farmer participation & location-specific interventions.
(M.A., 2019)	Mechanization in Bangladesh: A Way of Modernization in Agriculture.	Review of mechanization status and strategic analysis.	Low farm power (1.82 kW/ha) compromises land cultivation, productivity, and post-harvest losses.	Lack of skilled workforce, scarcity of engineering expertise, inadequate manufacturing infrastructure, and poor repair/maintenance services.	Promotional activities (training, subsidies), region-specific machinery selection, and R&D capacity building are critical for sustainable mechanization adoption.
(Wahab et al., 2011)	Manipulation of species combination for enhancing fish production.	Field experiments in 64 ponds across 4 agro-ecological regions.	Optimizing fish polyculture systems for ecological balance and income-protein security.	Complex species interactions; balancing cash crops (carps) and nutrition-focused species (SIS).	Species substitution (↑silver carp, ↑mrigal) increased total yield (19%) and income (27%) without disrupting SIS production for household nutrition.
(Bairagi et al., 2021)	Flood-tolerant rice improves climate resilience, profitability.	Endogenous Switching Regression (cross-sectional data).	Climate-induced flood losses; low adoption of stress-tolerant rice varieties.	Limited access to seeds/information, market instability, and input costs.	Sub1 rice adoption ↑yield (6%), ↑profit (55%), ↑household rice consumption (15%); adoption driven by neighbor networks, farmer groups, and training.
(Farouque & Takeya, 2009)	Extension workers' attitudes towards. The integrated soil fertility approach.	Survey of 64 extension workers (face-to-face interviews).	Poor dissemination of integrated soil fertility/nutrient management (ISF/NM) practices.	Lack of farmer training, weak extension contact, and insufficient institutional support.	68% of extension workers highly supported ISF/NM; farmer training and field visits were identified as the most effective dissemination tools.
(Kabir et al., 2017)	Farmers' perceptions of and responses to environmental change.	Field surveys in coastal villages.	Climate-induced salinization, flooding, and water scarcity are reducing crop viability.	Limited irrigation access, market instability, capital shortages, and weak extension services.	Farmers adopted trenching, stress-tolerant crops, and livestock diversification; they requested policy support for stress-tolerant seeds, irrigation, and price stabilization.

VI. CONCLUSIONS

This investigation has conducted a bibliometric analysis of 346 Scopus-indexed articles to gain a global insight and a clear understanding of the research trends in TDCP. The development of the field is encouraging, with an annual growth rate of 7.37%, indicating a growing interest in adopting agricultural technologies on a broader scale in crop production. Among the most significant contributors has been India, which has contributed to the list through its major agrarian institutions, including ICRISAT, Tamil Nadu Agricultural University, and ICAR-IARI. Kenya's research output, although low, is characterised by a very high international collaboration ratio and higher citation rates per article, indicating the importance of international collaborations in bridging knowledge gaps and maximising the impact of researchers in the country.

The thematic progression of research is one of the significant findings from the analysis. Earlier research in TDCP efforts focused on simple agricultural issues, whereas current studies tend to concentrate on global challenges, including climate change, food security, and sustainability. This emphasis is matched in practice by evidence from countries such as Bangladesh, where particular technological advances (including flood-tolerant rice and climate-resilient cropping systems) have helped to deliver concrete benefits in terms of agricultural productivity and farmer resilience. The interdisciplinary aspect of the field has also emerged through co-occurrence analysis, demonstrating the integration of ecological, technological, and socioeconomic elements in the present research. This systemic view is illustrated in the case studies on water management and polyculture optimization with a focus on the need for on-farm participatory trials and locally adapted technologies for successful technology uptake.

Indeed, while encouraging patterns of research productivity and collaboration are evident, there are also substantial deficits in the commitment to overcoming the long-standing obstacles to technology adoption. Critical constraints, such as poor infrastructure, restricted credit access, and inadequate extension services, have continued to limit the scale-up of agricultural technologies, particularly in resource-poor areas. Strikingly, market access and financing mechanisms to overcome these barriers have been underrepresented in the literature. This underscores a compelling need for future research to tackle these socio-political enablers of technology adoption, including gender-responsive finance and information-sharing digital platforms.

Ultimately, this study underscores the crucial role of research in shaping the trajectories of technology diffusion in crop production. Imagining the Changing Trends and Gaps in Lower-Middle-Income Countries: Such analyses present valuable data and could be instrumental in guiding future research foci, policy interventions, and partnership approaches. A coordinated approach that addresses the socioeconomic, infrastructural, and institutional constraints to technology uptake, as well as facilitating intersectoral collaboration, is crucial if the full benefits of agricultural innovations for food security, sustainability, and improved farmer livelihoods are to be realized worldwide.

VII. CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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