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Agricultural research and extension: trends and challenges in Peru and around the world (2015–2025)

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Agricultural extension, understood as producer-oriented guidance, is vital for driving technology adoption and sector development. This systematic review (2015–2025) examines global and national trends in agricultural research and extension, with a particular focus on Peru's policy landscape. Internationally, the U.S.A., China, and Europe are identified as leaders in scientific innovation, while Brazil excels regionally through its integrated approach to research, innovation, and extension. Agricultural research is still centralized in Lima on a national level, but expanding capability in areas like Amazonas, Junín, and Puno emphasizes how urgently decentralization is needed. By comparing national research output with MIDAGRI's Agrarian Development Plan 2021–2030 and relevant Sustainable Development Goals (SDGs), the study reveals strong thematic alignment in innovation, food security, and climate adaptation. Crucially, however, significant shortcomings are identified in governance and the effective inclusion of small-scale producers. Based on these findings, this study recommends strengthening decentralized R&D investment, fostering interregional research networks, and promoting strategic collaboration among universities, local governments, and rural communities. Ensuring the active participation of producers in the innovation cycle is essential for building a more inclusive, resilient, and effective agricultural extension system aligned with sustainable development goals.

KEYWORDS
agricultural extension, decentralization, inclusion, innovation systems, rural development, Peru

1 Introduction

Agriculture is vital for the food security and economic development of nations (Brenya and Zhu, 2023). Within this sector, agricultural extension involves processes that support and guide agricultural producers, with the goal of facilitating the adoption of knowledge and innovative practices. Strengthening agricultural extension is crucial, especially in developing countries, to counteract production stagnation, increase productivity, and increase farmers' per capita incomes (Aremu and Reynolds, 2024).

The transformation of the agricultural sector is closely linked to scientific progress and the effective implementation of innovative technologies (Silva et al., 2022; Fatemi et al., 2025). Accordingly, agricultural extension services play a fundamental mediating role by connecting technical knowledge with traditional production practices, which generates positive impacts on productivity and sustainability (Khushboo et al., 2023; Tham-Agyekum et al., 2024).

Historically, agricultural extension has evolved from empirical, localized knowledge transfer to a more structured and institutionalized process. The initial phase is defined by the empirical sharing of knowledge among farmers in a context lacking formal research and technology constraining productivity and excluding the most vulnerable groups. The transition phase introduces a more structured approach, incorporating extension services and technologies to increase the productive capacity of the agricultural sector. Finally, the contemporary phase leverages digital and technological innovation to advance agricultural extension as a more sustainable and participatory process, bridging the private and public sectors with a producer-centric focus (Briggs, 2009).

Agricultural extension services are particularly relevant in Latin America, as agricultural development is a cornerstone of the economy both for income generation and exports (Landini, 2016; Martínez-Dávila, 2018). However, this transformation process faces important challenges, including limited agent training and capacity, as well as insufficient consideration of region-specific sociocultural contexts, undermining intervention effectiveness. Despite these obstacles, Latin America has made encouraging progress in recent years, driven by stronger government policies and interdisciplinary collaboration.

In the case of Peru, the Ministerio de Desarrollo Agrario y Riego (MIDAGRI) plays a notable role in the design and implementation of policies and strategies for agricultural sector growth. These efforts are crucial for meeting the specific needs of resource-poor farmers and encouraging the adoption of sustainable and resilient agricultural practices. MIDAGRI's Agricultural Development Plan 2021–2030 outlines priorities and strategic guidelines to enhance farmers' skills, promote the incorporation of technologies, and foster innovative actions to increase sector competitiveness (MIDAGRI, 2021). In this context, the plan's relevance is invaluable, as it serves as a key instrument for achieving development objectives in the agricultural sector, including food security, poverty reduction, and gender equity in the country's rural areas.

Although the importance of agricultural extension and the increasing pursuit of innovative methods are recognized globally and in Latin America, a persistent gap remains in the effectiveness of agricultural innovation. While studies such as those by Hellin (2012) and Martínez-Dávila (2018) have provided valuable insights into trends, challenges, and specific cases, comprehensive analyses that capture the true state of scientific innovation in agriculture and propose solutions that are applicable in both global and national contexts are still lacking. This limits the identification of best practices, the understanding of key contextual factors influencing intervention success, and ultimately, the development of more effective extension policies and strategies tailored to Peru's reality.

Thus, this systematic review aims to address this knowledge gap by providing a comprehensive, comparative analysis of agricultural extension progress within both global and national frameworks, specifically focusing on MIDAGRI guidelines and studies from 2015 to 2025, to identify advancements and persistent gaps. This will enable evidence-based evaluation and guidance for strengthening agricultural extension policies and strategies in Peru.

2 Methods

2.1 PICOS review and formulation

This study addresses agricultural research and extension holistic framework, with a specific focus on Peru and a comparison of key global and regional trends (Africa, Asia, Europe, North America, and South America). The intervention centers on agricultural innovation trends, covering critical topics such as technology adoption, sustainability, and climate adaptation, in addition to analyzing agricultural extension policies, with special attention to decentralization and governance processes. The main comparison is established between international R&D trends and the Peruvian landscape, evaluating the alignment of national studies with formulated guidelines. The results, obtained through a systematic review of articles published from 2015 to April 2025, reveal the impact on sector governance, the inclusion of small-scale producers, the decentralization of research capacity, and the alignment of scientific output with the pressing needs of the Peruvian agricultural sector.

2.2 Analysis and selection of objectives, guidelines and strategic guidelines

As a first methodological step, we conducted a detailed analysis of the three main objectives outlined in MIDAGRI's Agrarian Development Plan 2021–2030 (MIDAGRI, 2021): (OP1) increasing the integration of agricultural producers into the value chain, (OP2) promoting the prosperity of subsistence family farmers, and (OP3) reinforcing institutional coordination for agricultural production. These objectives are articulated through 14 strategic guidelines (L1–L14), which were organized, systematized, and subsequently synthesized into 10 key directives that served as the core of our analytical framework. The formulation of these guidelines took into account the Sustainable Development Goals (SDGs), specifically goals: hunger eradication (SDG 2), gender equality (SDG 5), water management (SDG 6), decent work (SDG 8), innovation (SDG 9) and reduced inequalities (SDG 10), ensuring our analysis aligned with both national priorities and global sustainability frameworks. These directives expand upon and operationalize the scope of the objectives proposed by MIDAGRI (Figure 1A). The 10 strategic directives defined in this study formed the analytical framework for selecting, classifying, and evaluating the research included in the review. These directives cover the following thematic areas: small-scale producer inclusion (O1); food security (O2); access to services and resources (O3); efficient natural resource management (O4); territorial planning (O5); strengthening organizations and cooperatives (O6); digitalization, technology, and innovation (O7); climate change adaptation (O8); governance and institutionality (O9); and gender equity and rural youth participation (O10) (Figure 1B). This set of directives allowed us to establish criteria for coherence and thematic relevance in the bibliographic review and its subsequent analysis.

2.2.1 Search strategy, source and quality of data, and risk of bias

This study adhered to the methodological guidelines established for systematic reviews, including the PRISMA 2020 statement, with the objective of identifying, selecting, synthesizing, and

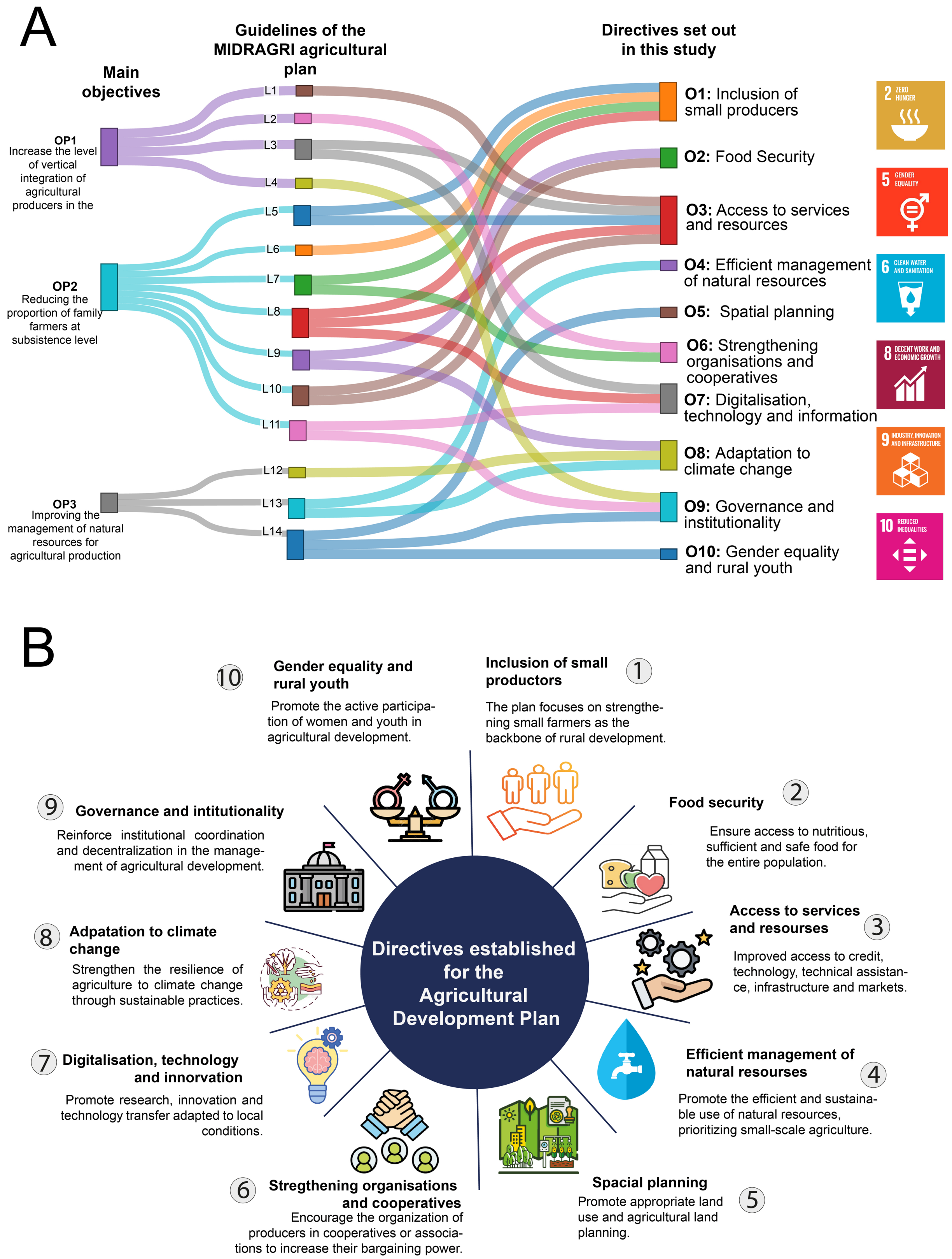

FIGURE 1
Data extraction strategy. Analyzing the plan's guidelines to establish the 10 strategic directives for this study and detailing the directives established in this study, including a description of the scope of each **(A)**. Process of formulating and describing the guidelines for the Agricultural Development Plan. Structural link between sectoral objectives (MIDAGRI) and the guidelines established in this study **(B)** and detailing and scope of the 10 guidelines established for the agricultural development plan.

consolidating the evidence on R&D and agricultural extension in Peru within global contexts. The search strategy was designed in stages to address the global and national contexts separately, ensuring comprehensive coverage and academic rigor. For the global context, we examined scientific articles indexed in Scopus and Web of Science, prioritizing academic rigor and indexing in Q1-Q2 journals. For the national context, given the scarcity of national studies published in indexed journals, the search was strategically expanded to SciELO, Google Scholar, and the official websites of relevant governmental and non-governmental organizations (e.g., MIDAGRI, INIA, FAO, World Bank, IDB), in order to incorporate the critical gray literature for policy analysis (Gusenbauer, 2019).

The search was conducted until April 14, 2025, covering an analysis period starting in January 2015. This timeframe enables to appreciate trends and significant changes over a decade. To refine the identification of relevant studies, Boolean operators (e.g., "AND," "OR") and a combination of keywords were employed, including the geographical and governance component that was omitted in the initial version, based on the PICOS framework: ("agricultural extension" OR "extension services" OR "farmers") AND ("innovation" OR "technology transfer" OR "technology adoption" OR "impact"). This approach produced 332 national studies and 3,225 international studies, including book chapters, articles, and reviews. The selection process involved the extraction of all references and data compilation into spreadsheets. To mitigate the risk of bias and evaluate the quality of the evidence, a dual process was implemented: a) Primary studies were assessed using the Mixed Methods Appraisal Tool (MMAT) to validate their methodological rigor, b) gray literature was evaluated through an adapted protocol focused on institutional origin, authorship, and the clarity of the evidence base, in order to detect and document potential advocacy or institutional publication biases, ensuring a critical and evidence-based synthesis.

2.3 Data inclusion criteria

Importantly, to ensure the applicability of international findings to Peru's context, they need to be analyzed through the lens of this study's 10 strategic guidelines. While sustainability objectives hold global relevance, Peru's unique agricultural challenges demand a tailored approach aligned with national priorities. This methodology facilitates the adaptation of global solutions to local realities, thereby enhancing their contribution to the objectives of MIDAGRI. Although these objectives maintain alignment with international goals, they require careful contextualization of Peru's distinct socioeconomic and environmental conditions. This approach ultimately strengthens the relevance and potential impact of research on sustainable agricultural development in Peru.

The screening process yielded 3,225 international and 332 national studies. This initial filtering eliminated duplicate publications, book chapters, and nonagricultural studies, narrowing the selection to relevant research. Six independent reviewers evaluated the studies by examining titles, keywords, abstracts, and conclusions. Additionally, they assessed each study's alignment with the 10 predefined strategic guidelines. To streamline the analysis, the retrieved data were coded according to these guidelines and keyword frequency to identify recurring themes (Staartjes et al., 2022). This systematic approach resulted in the final selection of 2,169 international and 232 national studies (Figure 2B).

2.4 Data analysis

After collecting, identifying, and cleaning the data, we conducted thematic analysis. For effective visualization of the results, we generated heatmaps, bar charts, and geographic distribution maps using RStudio v.4.2.3 (Posit team, 2023). This analysis employed the following R packages: ggplot2 for visualizations (Wickham, 2016), dplyr for data manipulation (Wickham et al., 2023), tidyr for data organization (Wickham et al., 2023), and ade4 for multivariate analysis (Bougeard and Dray, 2018). The final synthesis was conducted through narrative analysis, providing a systematic and structured interpretation of findings across all included studies (Figure 2C).

2.5 Methodological flow

The methodology used in this review was organized into three key phases: (i) the identification and definition of the search strategy and the development of the data quality assessment; (ii) the screening of studies against the inclusion/exclusion criteria; and (iii) the final analysis of the included data (Figure 2).

3 Results

3.1 Agriculture research in worldwide context

An analysis of the 2,270 investigations from the last 10 years reveals consistent trends among the leading countries in agricultural research and extension. Figure 3, which uses varying intensities of blue tones, illustrates this scientific production over the decade. This shows that countries such as the United States and China maintain clear leadership with their high scientific output (e.g., 112–243 studies), followed by European nations such as the United Kingdom and Germany (e.g., 71–112). In stark contrast, Peru ranks among the countries with the lowest scientific production in high-impact agricultural extension research, a situation shared with several other South American nations, including Ecuador, Chile, Argentina, and Uruguay.

With respect to each country's scientific production, the United States and China are notable for their sustained growth over the last decade. In South America, Brazil has emerged as a leader in recent years, driven by its scientific output and upward trend. These findings indicate an advancement in Brazil's research capabilities during the analyzed period (Figure 4). Conversely, Europe, exemplified by Germany and the Netherlands, shows stable production, albeit with a slight deceleration compared with that of global leaders. Projections for 2025 suggest a strengthening of China's leadership and progressive growth among developing countries in Asia and Latin America, fueled by international partnerships and access to emerging technologies. This outlook points to a greater diversification of scientific knowledge and a shift toward a more equitable global distribution of research (Figure 4).

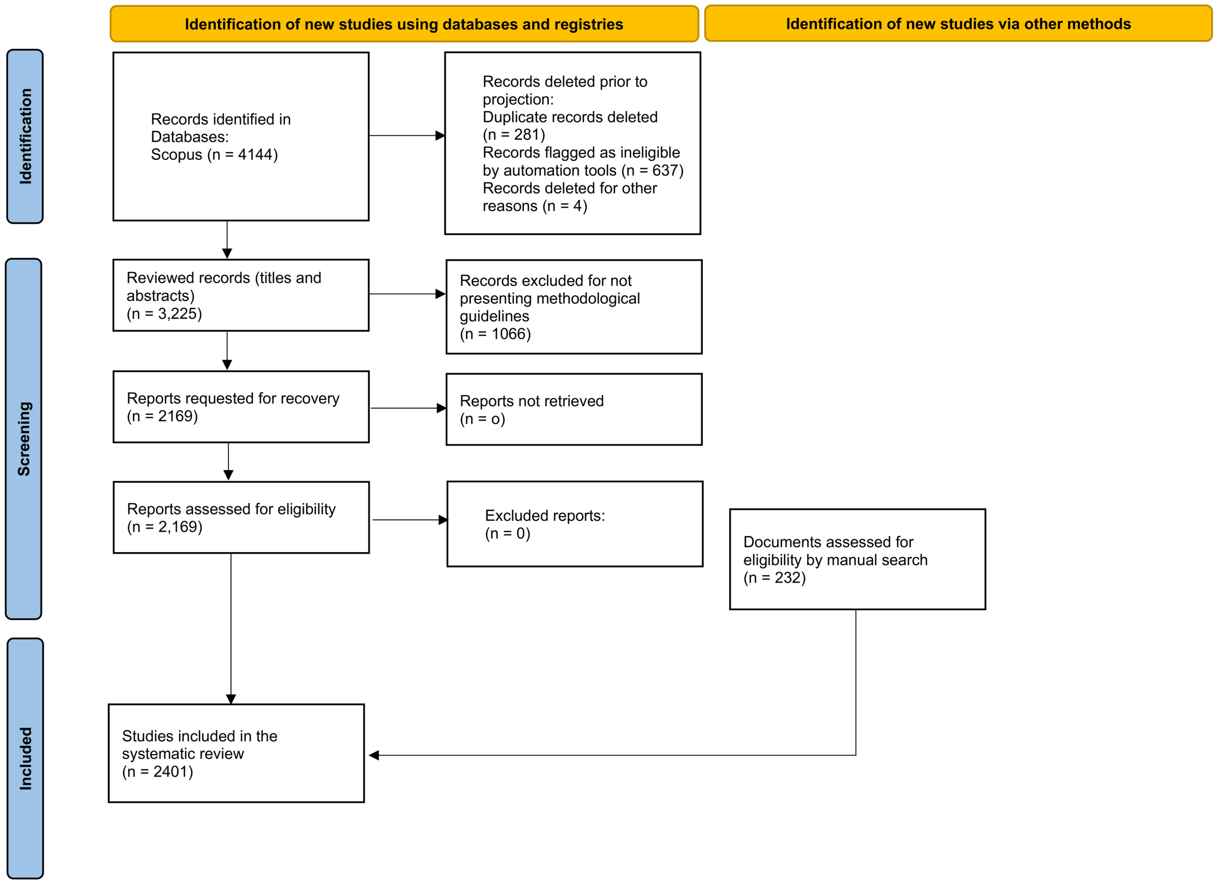

FIGURE 2
Flow diagram summarizing the methodology applied in this study.

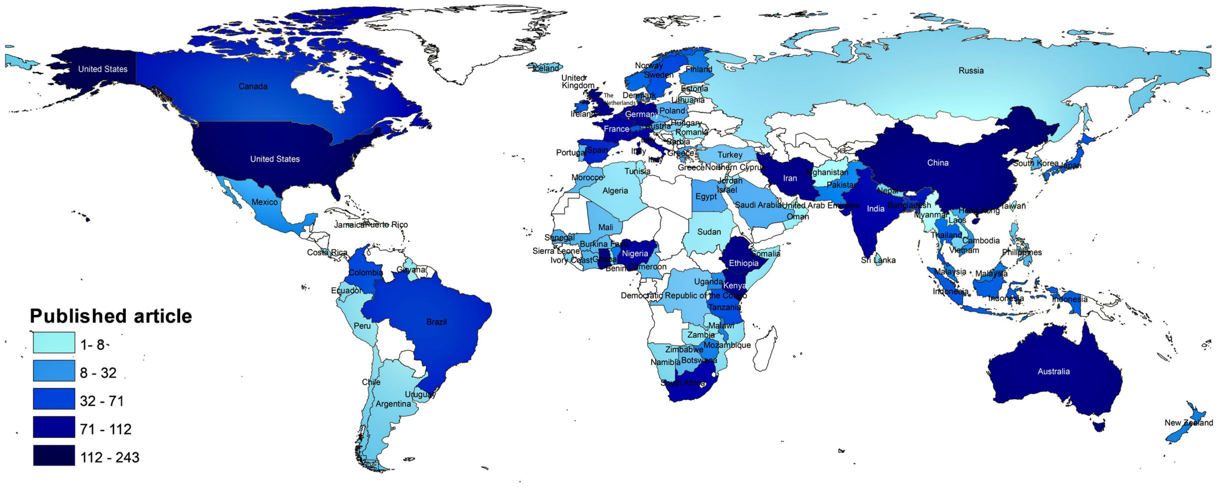

FIGURE 3
Scientific production from 2015 to 2025 related to agricultural extension. The intensity of the blue tones is related to the highest scientific production.

3.1.1 Scientific production and strategic guidelines

The analysis of scientific production between 2015 and 2025 in relation to the objectives of MIDAGRI's Agricultural Development Plan 2021–2030 is presented in Figure 5. The figure highlights that the guidelines concerning "inclusion of small producers," "food security," and "adaptation to climate change" were consistently studied throughout the analyzed period. Furthermore, the strong emphasis on

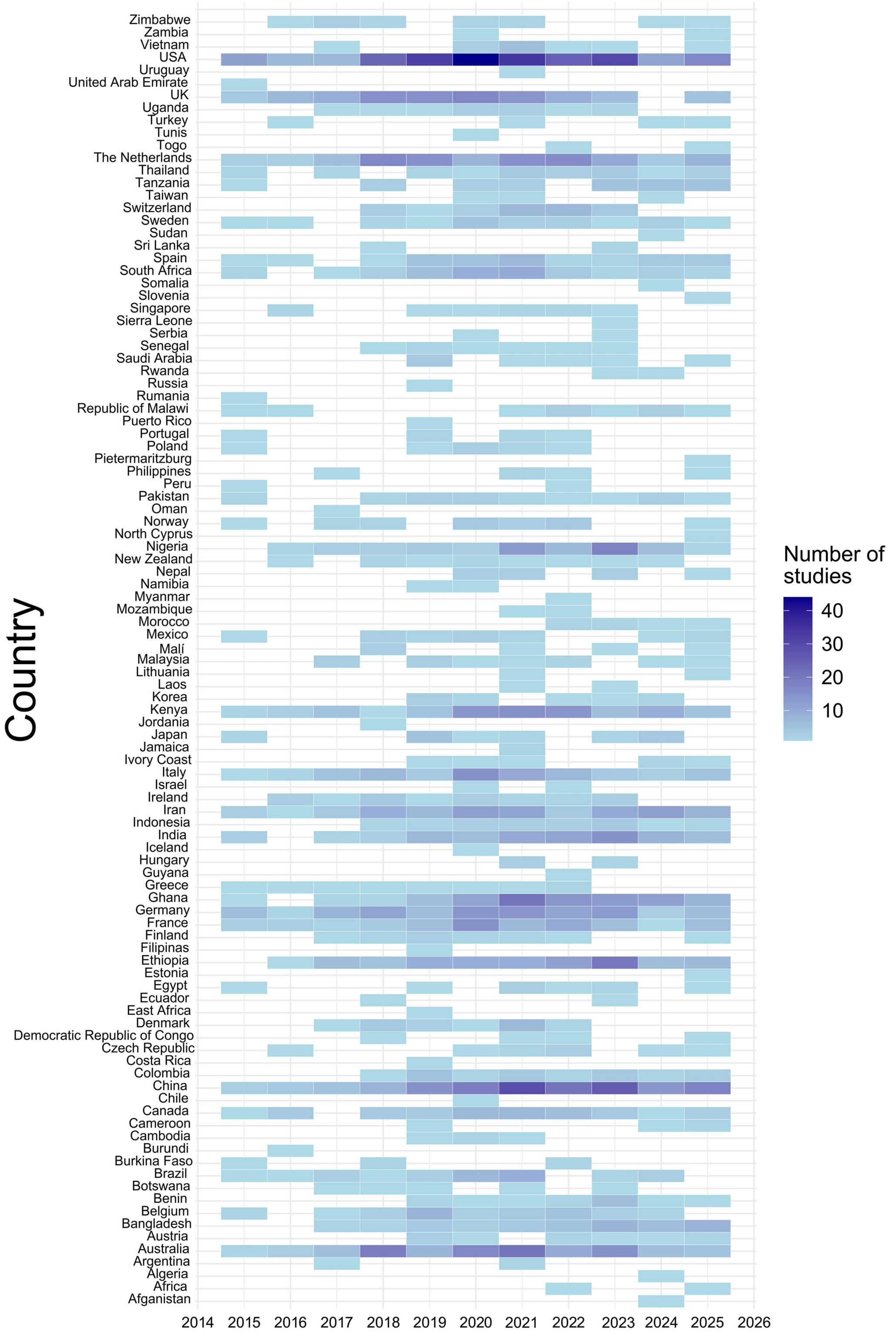

FIGURE 4
Heatmap between years and scientific production of each country. The intensity of shades (blue) corresponds to the highest scientific production.

"digitalization, technology, and innovation" indicates these objectives' priorities and continued relevance in academic research. Conversely, studies on "gender equality and rural youth" and "governance and institutionality" showed fluctuations in annual publications from 2021 to 2023. Nevertheless, the period revealed an increase in publications focused on "efficient management of natural resources" and "food security." This surge reflects a response to emerging environmental challenges and a heightened global awareness of sustainability.

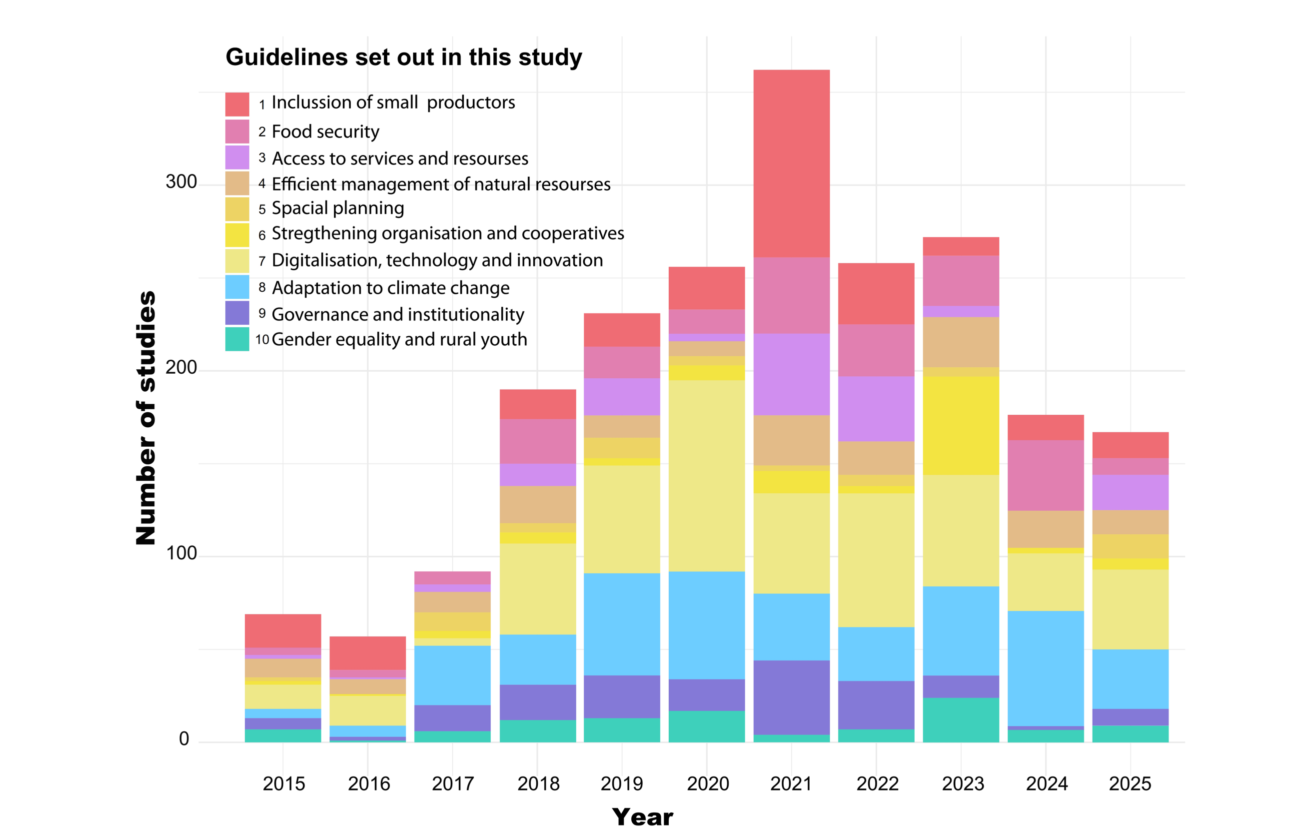

FIGURE 5
Scientific production in relation to the years and objectives established through the 10 guidelines established in this study.

3.1.2 Worldwide scientific production and keywords

An analysis of keyword usage in scientific research from 2015 to 2025 reveals that terms such as "technology adoption," "innovation," "impact," and "farmer" maintained a consistent presence throughout the study period. Conversely, the keyword "technology transfer" exhibited notable changes during this time (Figure 6A). 2023 notably had a significantly high incidence of all studied keywords compared with prior years, indicating a surge in scientific production across a broad range of topics. Overall, Figure 6 illustrates a general increase in the use of certain keywords over time, whereas others remained relatively constant.

The Venn diagrams in Figures 6B,C demonstrate significant thematic overlaps in keyword usage within the agricultural scientific literature. Each ellipse represents a key term, with its size corresponding to the term's frequency and the overlapping areas indicating co-occurrence rates between terms. The analysis of keyword prevalence in agricultural research reveals several consistent patterns across the literature. Five terms emerge as particularly prominent: "farmer," "impact," "technology transfer," "technology adoption," and "innovation." A notable 28% co-occurrence rate between "farmer" and "impact" underscores the field's focus on agricultural outcomes and effectiveness. Similarly, the relationship between "technology transfer" and "technology adoption" (4%) reflects ongoing scholarly interest in technological dissemination processes. Most significantly, the term "farmer" demonstrates remarkable conceptual centrality, appearing in 39% of studies and in 58% of study cases, highlighting its fundamental role in contemporary agricultural research.

3.1.3 Research output trends among leading agricultural institutions (2015–2025)

An analysis of the 12 institutions most frequently focusing on producers or the agricultural sector from 2015 to 2025 reveals a notable increase in their research output in 2021 and 2023 compared with other years within the period (Figure 7). Among these, Wageningen University & Research (WUR) in the Netherlands, a top-ranked institution in agriculture and related fields, has significantly contributed to agricultural extension studies, often emphasizing sustainable agricultural production systems and knowledge transfer to low- and middle-income countries. Additionally, African institutions such as the University of Ghana (known for its School of Agriculture and Research Centers such as the Soil and Irrigation Research Centre) and the University of Nairobi have demonstrated a continuous rise in agricultural research. Similarly, Asian institutions have expanded their generation of scientific knowledge aimed at agricultural development, with organizations such as the Asian Development Bank (ADB) actively supporting food system transformation in the region, as shown in Figure 7.

An examination of the scientific articles produced by the 22 institutions with the highest global production reveals how these studies align with the MIDAGRI Agricultural Development Plan 2021–2030 guidelines (Figure 8). The data, visualized by the

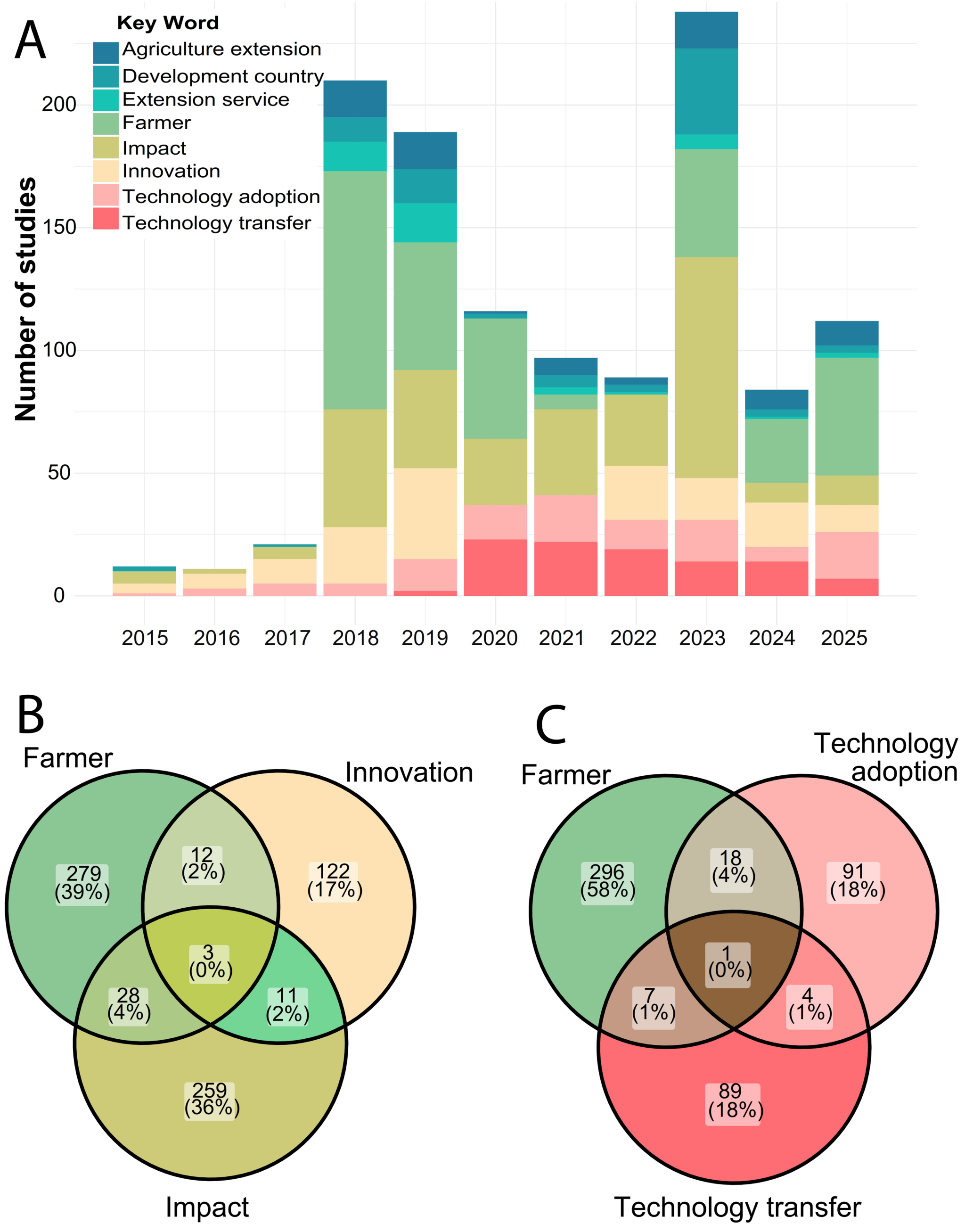

FIGURE 6
Worldwide scientific production related to keywords applied in the search for studies. Evolution of word usage from 2015 to 2025 **(A)**; co-occurrence of the words "farmer," "innovation," and "impact" **(B)**; and co-occurrence of the words "farmer," "technology adoption," and "technology transfer" **(C)**.

intensity of green shades, indicate a high concentration of research around guidelines such as "inclusion of small producers," "digitalization," "adaptation to climate change," and "efficient management of natural resources." Furthermore, institutions in both industrialized nations and those in regions heavily dependent on agriculture show strong alignment with the "inclusion of small producers" and "food security" guidelines. Conversely, institutions in more technologically developed countries have different emphases, particularly regarding "technology" and "adaptation to climate change." Notably, Wageningen University (WUR) stands out for its high intensity across multiple guidelines, underscoring its leadership and comprehensive approach to agricultural research that aligns with sustainable development goals, as illustrated in Figure 8.

An analysis of the scientific outputs of the top 20 institutions reveals the frequent co-occurrence of keywords such as agricultural extension, farmer, impact, and innovation in their publications. Figure 9 visualizes this trend through varying shades of blue, where darker intensities represent higher study volumes. Notably, institutions such as the University of Ghana, the International Institute of Tropical Agriculture (IITA), and the International Maize and Wheat Improvement Center (CIMMYT) have made substantial contributions

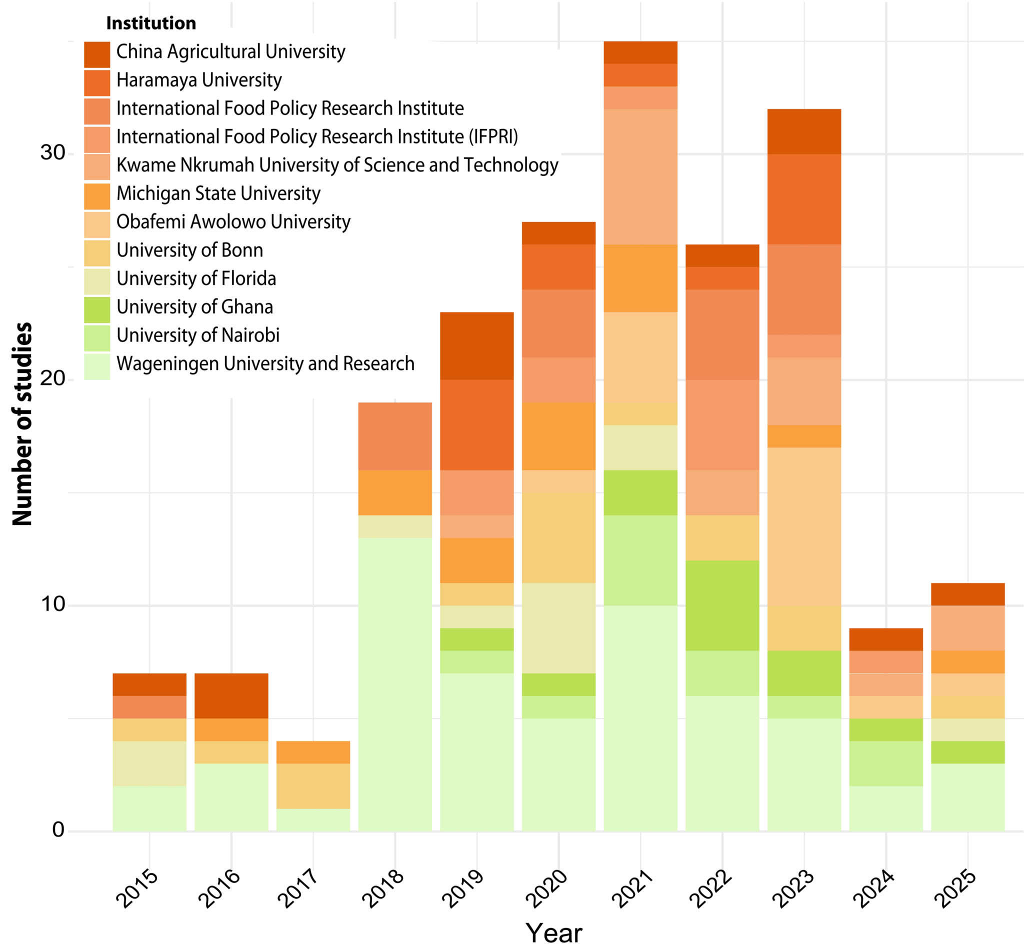

FIGURE 7
Scientific production of the 12 best institutions worldwide.

to these research themes. The figure further highlights the growing role of African, Asian, and European institutions in agricultural research over the past decade. Among these, the Agricultural University of China, the University of Bonn, and Wageningen University & Research have emerged as leading producers of high-impact studies, reinforcing their global influence on agricultural innovation and technology transfer.

3.2 Agriculture research in the Peruvian context

Our analysis of 232 national studies conducted between 2015 and 2025 reveals significant insights into Peru's scientific output. Figure 10A visually represents the geographic distribution of this scientific production across the Peruvian territory, utilizing an intensity of light blue to blue shades to highlight notable regional differences. The Lima region, for example, leads with the highest scientific output (32–79 studies), followed by the Amazonas region (northern zone) at 16–32 studies. Furthermore, Figure 10B underscores the pivotal contribution of the National Institute for Agrarian Innovation (INIA). Owing to its decentralized presence, the INIA plays a fundamental role in generating research in science, technology, engineering, mathematics (STEM) and research and development (R&D) across most regions. Its involvement is particularly significant in Ica, La Libertad, Moquegua, and Ucayali, with notable contributions also observed in Ancash, Amazonas, Huánuco, Loreto, and Piura. Finally, Figure 10C illustrates the evolution of scientific publications by institution, identifying INIA, the Research Institute for Sustainable Development of Ceja de Selva (INDES-CES UNTRM), and the National University of Piura (UNP) as key players in agricultural scientific production.

3.2.1 Scientific production and strategic guidelines

The analysis of scientific production trends in relation to the 10 strategic guidelines established in this study is presented in Figure 11. The results show that guidelines such as "efficient management of natural resources" and "spatial planning" were predominantly addressed throughout the analyzed period, reflecting a sustained focus on optimizing resource utilization and land-use planning within agricultural development. Conversely, the "governance and institutional framework" guidelines recorded no publications across any year, indicating limited scientific output concerning administrative management, regulatory frameworks, and institutional policies in the agrarian sector (Figure 11).

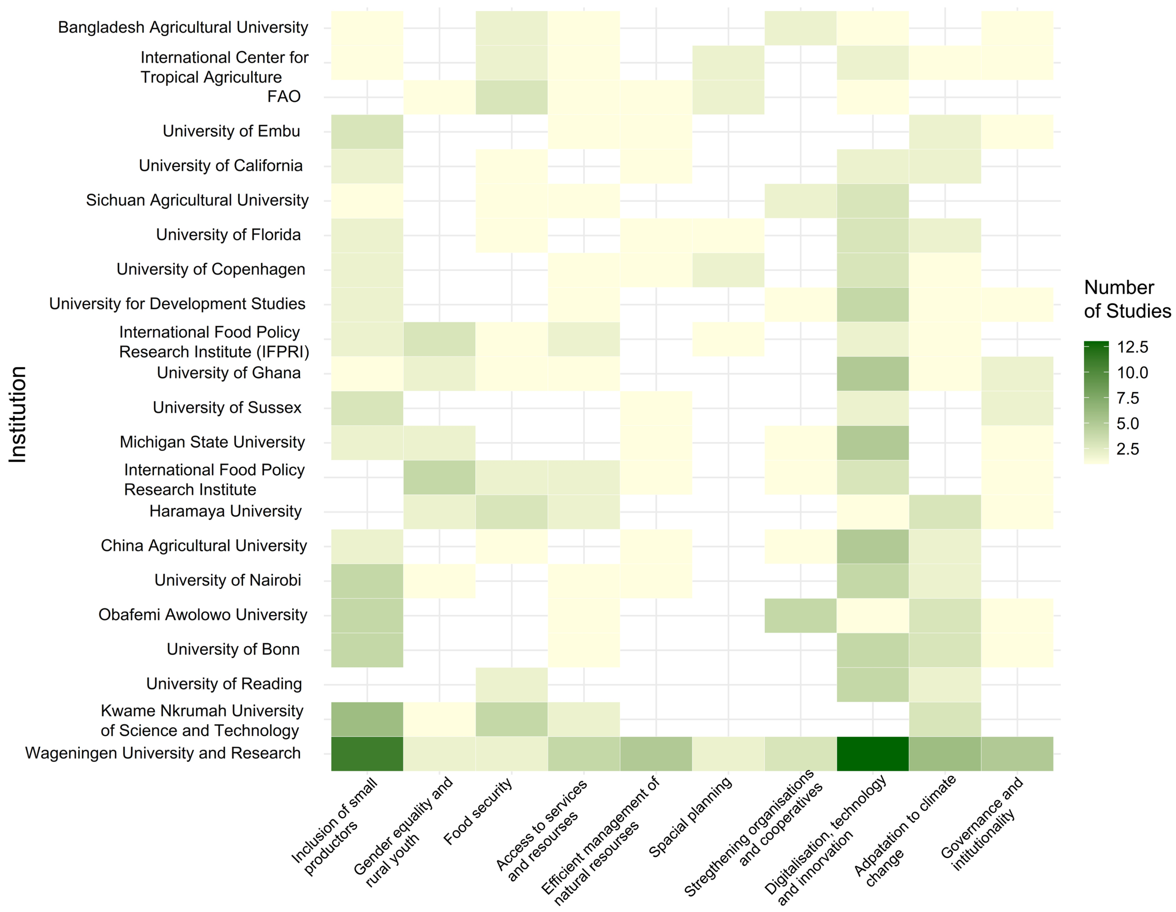

FIGURE 8
Scientific production of the 22 most relevant institutions worldwide in relation to the strategic guidelines established through the 10 guidelines established in this study.

3.2.2 Scientific production and keywords

The analysis of Peruvian scientific output (Figure 12A) revealed "impact" as the predominant keyword throughout the study period, with notable publication peaks from 2020 to 2021. This pattern reflects the research community's sustained focus on assessing agricultural technologies, policies, and practices. In contrast, the term "developing country" appears only sporadically (2020–2021), whereas the complete absence of "extension service" terminology indicates minimal research attention to agricultural technology dissemination systems. These findings suggest a research landscape prioritizing impact assessment over both comparative development studies and extension mechanism analysis, potentially highlighting gaps in Peru's agricultural research agenda.

The Venn diagrams in Figure 12B demonstrate significant thematic overlaps in Peruvian agricultural research, with persistent use of four key terms: "impact," "innovation," "developing country," and "technology adoption." The analysis reveals particularly strong conceptual linkages between (1) impact and innovation (20% co-occurrence) and (2) technology transfer and adoption (4% co-occurrence). Most notably, Figure 12C shows that 41% of the studies address the triad of "developing country," "innovation," and "impact" a finding that underscores how contemporary Peruvian agricultural research fundamentally intersects developmental priorities, technological advancements, and outcome evaluations. These patterns collectively reveal a research landscape that prioritizes practical applications within Peru's developmental context while maintaining a focus on measurable results.

3.2.3 Scientific production of the main Peruvian institutions

The publication output of Peru's 12 most productive research entities from 2015 to 2025 (Figure 13) revealed a notable surge in overall scientific production by 2024 compared with previous years. The National Institute for Agrarian Innovation (INIA) has maintained consistently high research output related to agricultural extension since 2019, whereas universities, including INDES-CES UNTRM and UNP, demonstrated steady growth in scientific publications throughout the period. This upward trajectory reflects both increasing research activity and greater investment in agricultural science and technology, projecting continued expansion through 2025. This production dynamic reflects a progressive growth in the number of research projects by 2025, which indicates an increase in investment in science and technology in the agricultural sector. Additionally, the presence of leading institutions in the national scientific landscape points to a solid and evolving academic ecosystem.

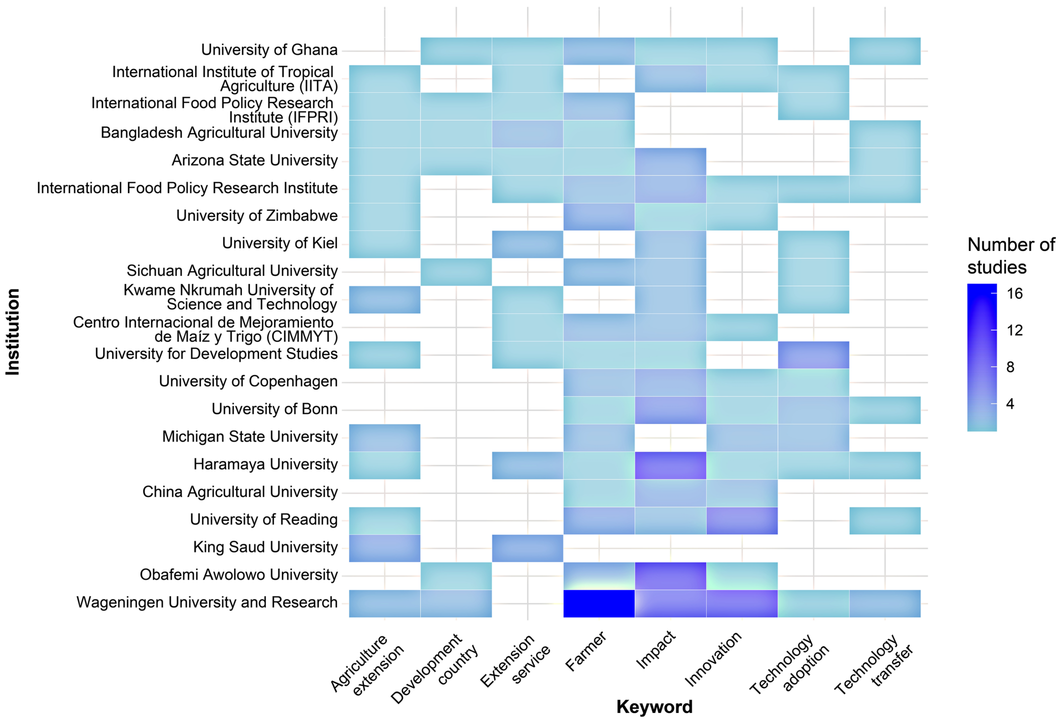

FIGURE 9
Heatmap of the number of publications in the top 22 institutes worldwide in relation to the keywords considered for this study.

The evolution of scientific production related to this study's keywords reveals an alignment between research driven by Peruvian institutions and the guidelines established in the MIDAGRI 2021–2030 Agricultural Development Plan. In this context, the guidelines linked to digitalization, technology and innovation appear most frequently, demonstrating a predominant emphasis on generating and applying new technologies (Figure 14).

This pattern reinforces Peruvian institutions' commitment to global innovation trends in agriculture. However, studies on governance and institutional frameworks are lacking. This gap may result from limited funding for research on agricultural policies and sector administration, reflecting a deficiency in developing institutional strategies for agricultural management. The lack of studies in this area could hinder the effective implementation of public policies and regulations. These findings suggest the need to (i) rebalance research funding allocation and (ii) promote studies in underresearched areas such as governance while strengthening initiatives addressing emerging agricultural challenges.

An analysis of research trends and institutional study distribution by keyword reveals key insights into scientific production. Entities such as the Research Institute for Sustainable Development of Ceja de Selva (INDES-CES), the National Agrarian University La Molina (UNALM), and the National Institute of Agrarian Innovation (INIA) demonstrate a significant number of investigations related to fundamental aspects such as "natural resource management," "food security," and "adaptation to climate change." Conversely, some institutions exhibit a lower research presence within the keyword matrix, notably the National University of San Martín (UNSM). The absence of certain keywords, specifically "agricultural extension" and "extension service," among the studies from particular institutions suggests a diminished focus on research applied to the modernization of the agricultural sector. These trends and institutional distributions are illustrated in Figure 15.

4 Discussion

This systematic and comparative review (2015–2025), guided by the PRISMA 2020 Statement, rigorously analyzed the progress of agricultural extension under global and national guidelines. The results confirm a marked alignment of the Peruvian sector with technological modernization and climate resilience, but reveal that chronic institutional fragmentation and the centralization of scientific output in the capital systematically undermine these efforts. The study's main novelty lies in identifying that the persistent gap is not technological but is rooted in governance and equity, manifesting as an ineffective hierarchical (top-down) extension model. This approach not only decapitalizes local knowledge but also exposes family agriculture to an unacceptable economic and social risk by failing to integrate basic and applied research.

4.1 International and national contexts

In the last decade, the scientific production leadership shown by the United States and China is not merely a quantitative measure but a direct consequence of sustained, strategic investment in R&D, reflected in cutting-edge infrastructure, top talent attraction, and significant project funding (Lancho-Barrantes et al., 2021). These strategies not only guarantee food security and economic

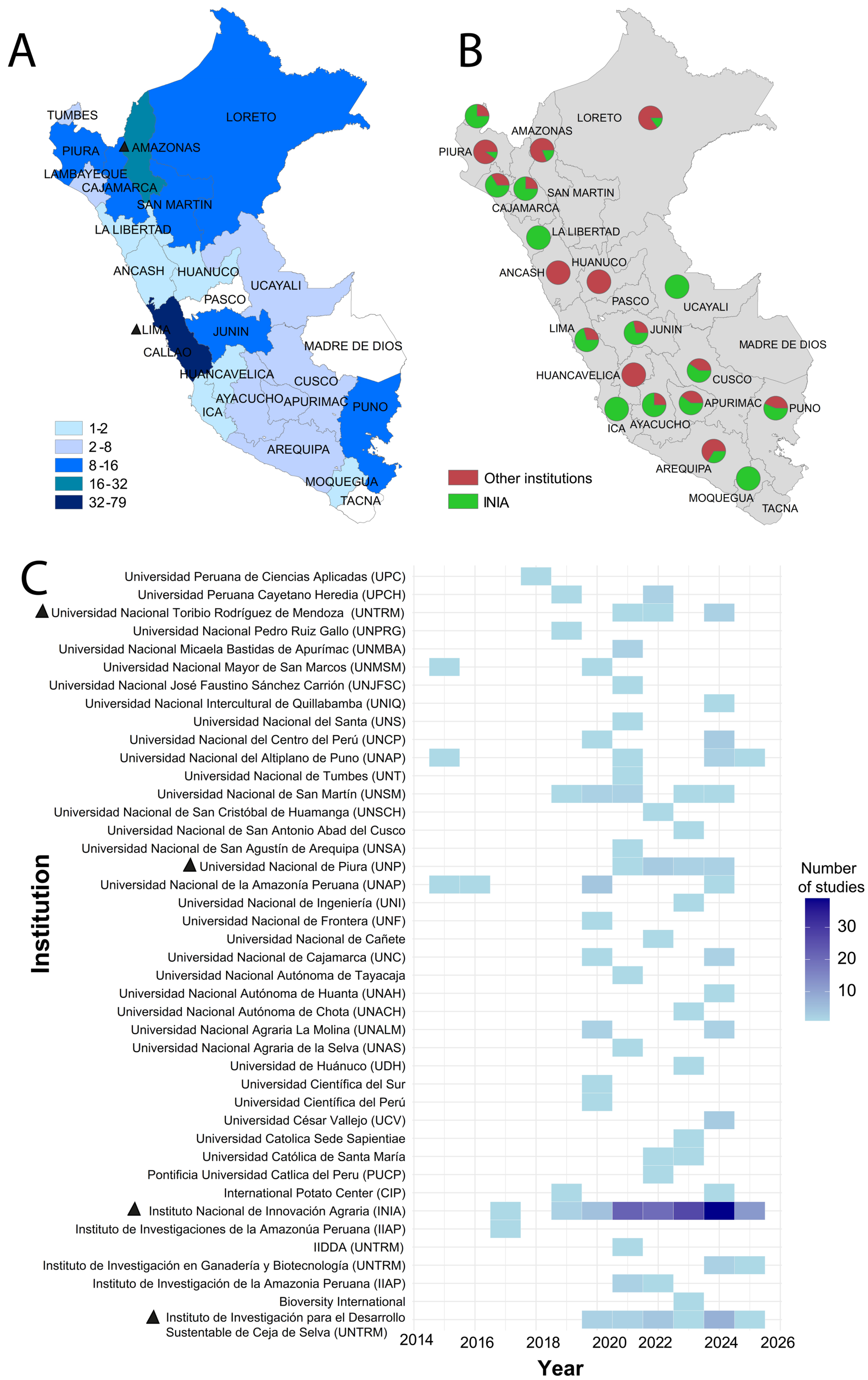

FIGURE 10
Peruvian scientific production related to agriculture; the best institutions are marked with a triangle. Scientific production from 2015 to 2025 **(A)**; regional contribution from the National Institute for Agrarian Innovation (INIA) and other institutions related to agriculture **(B)**; and evolution and number of publications by year and institution **(C)**.

competitiveness but also place both nations at the technological cutting edge through the application of biotechnology, precision agriculture, and deep learning (AI) in agriculture (Mizik, 2021; Pawlak and Kołodziejczak, 2020).

While Europe's robust presence relies on a well-established knowledge base (Belderbos and Somers, 2018), its slight slowdown suggests a vulnerability in adapting research priorities to rapidly emerging contemporary challenges. Critically, Brazil's substantial development, rooted in extensive natural resources, underscores the positive and necessary impact of a highly coordinated national approach to agricultural R&D (Pivoto et al., 2018; French et al., 2024). Thus, the sustained expansion of agricultural research in Asia and

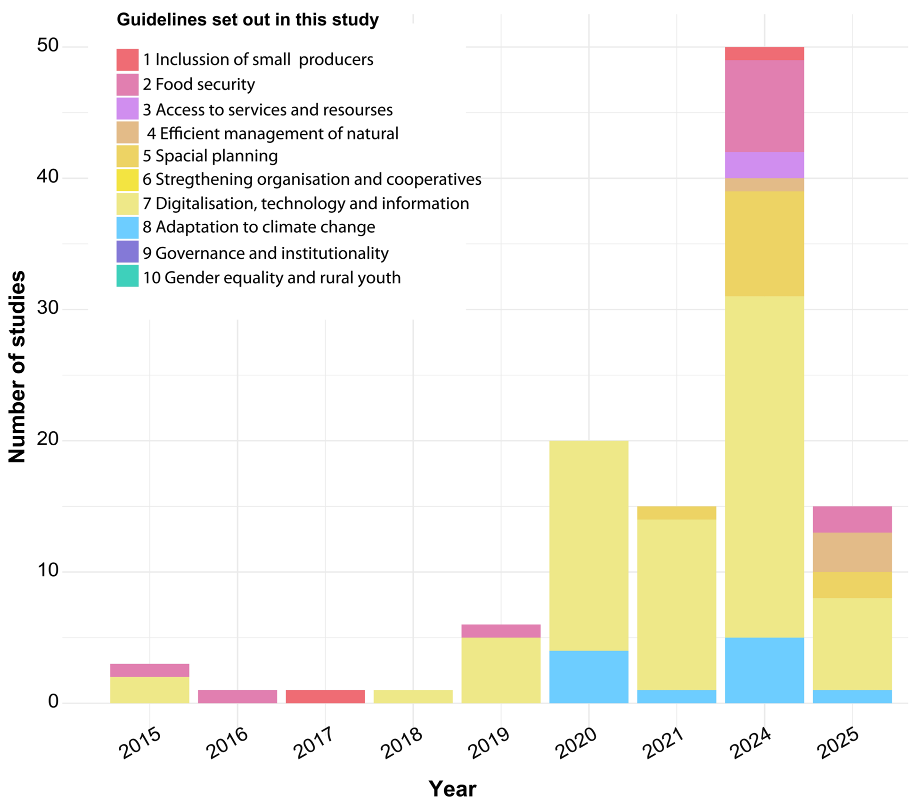

FIGURE 11
Scientific production in the Peruvian territory highlights the most relevant guidelines in the last 10 years.

Latin America, driven by international alliances, must be viewed as a strategic necessity for convergence for developing nations such as Peru (Habib-ur-Rahman et al., 2022; Momenpour et al., 2024).

While Peruvian scientific output in the agricultural sector is primarily concentrated in the capital, Lima (Miranda Valdivia, 2017), this centralization—despite fostering interinstitutional collaboration and the accumulation—must be critiqued as a structural constraint that undermines national effectiveness. This geographic intellectual stratification in Lima poses a severe and counter-productive challenge by failing to produce solutions genuinely tailored to the country's profound and diverse agricultural landscape. This results in a critical mismatch between centralized capacity and territorial necessity. Although the significant scientific output from regions such as Amazonas, Junín, and Puno stands out as a positive indicator, pointing to the presence of regional centers of excellence driven by specific needs, this should be interpreted less as a sign of systemic robustness and more as evidence of isolated regional centers forced to address specific needs (Habib-ur-Rahman et al., 2022). This pattern ultimately confirms that the central system fails to adequately prioritize or integrate the heterogeneous demands of the national agricultural sector.

4.2 Scientific production and strategic guidelines

An analysis of scientific output from 2015 to 2025 reveals a dynamic landscape for agricultural research. Globally, topics such as "inclusion of small producers," "food security" and "access to resources" have maintained a continuous presence, solidifying their role as fundamental pillars for the sustainable development of the agricultural sector (Mizik, 2021). In contrast, research areas such as "gender equity," "rural youth," and "governance" show fluctuations in their scientific output, reflecting shifts in researcher interest over time regarding the integration of gender equity into agricultural policies and research (Acosta et al., 2025). However, the notable increase in research on "efficient natural resource management" and "adaptability to climate change" represents a logical and necessary trend driven by growing global concern for environmental sustainability. Nonetheless, the heterogeneity of methodological approaches, the uneven incorporation of social dimensions, and the reactive orientation of climate-related research reveal persistent gaps in coherence and strategic alignment. This fragmentation limits the comparability of findings across studies and constrains their translation into policy-relevant evidence, highlighting the need for more integrated and equity-centered research agendas.

In Peru, researchers most frequently address topics that reflect a practical focus on "spatial planning" and "resource management." This orientation is shaped by the country's diverse geographical environment and the need to optimize the use of resources such as land and water (Abdenur et al., 2019; Verjel and Vieira, 2024). These trends reflect an evolution in research priorities, underscoring sustainability and agricultural resilience. In this context, it is crucial for Peru to guide future research strategies and resource allocation (Morales, 2022) to strengthen research in areas such as "governance and institutionality." This strategic guidance must include as an

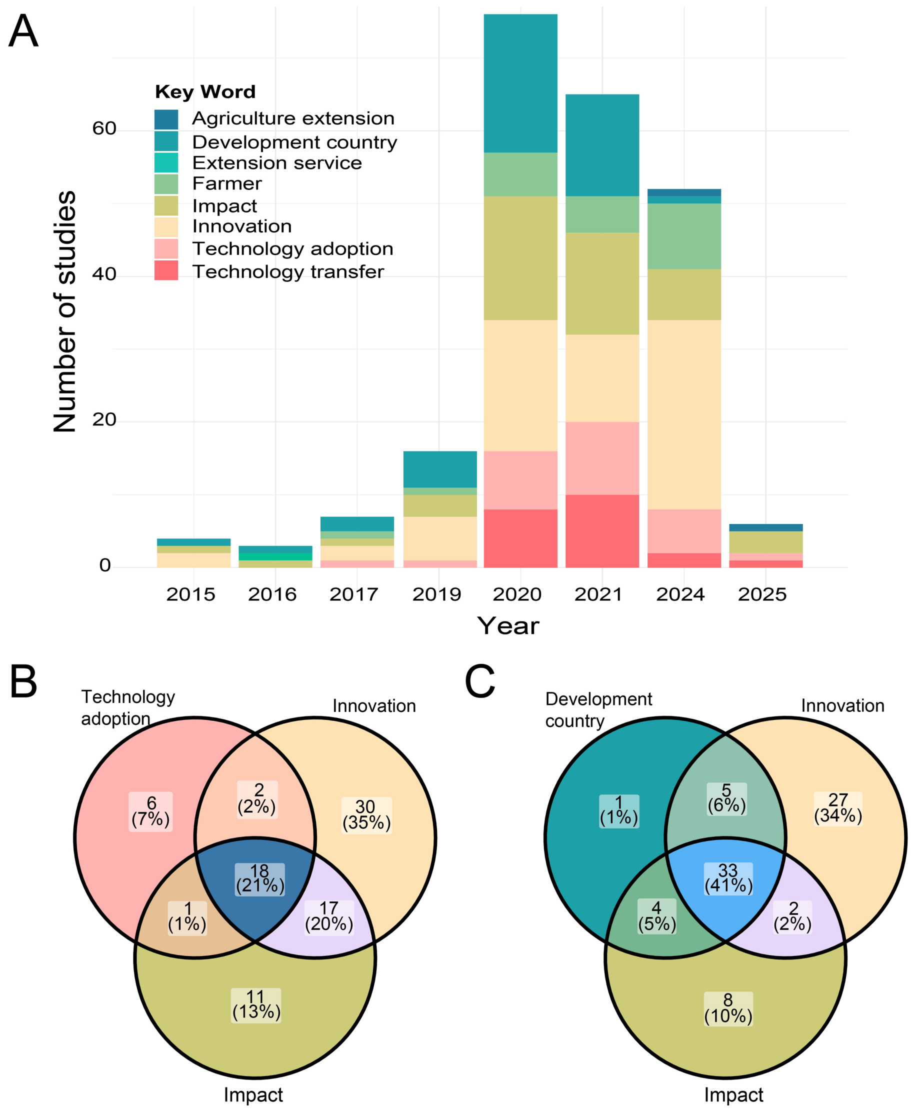

FIGURE 12
Association graphs of the most commonly used keywords in scientific production from 2015 to 2025 in Peru. Evolution of word usage from 2015 to 2025 **(A)**; co-occurrence of the words "technology adoption," "innovation," and "impact" **(B)**; and co-occurrence of the words "developing country," "innovation," and "impact" **(C)**.

imperative the mitigation of economic and social risk through investment in high-resolution basic and applied research, ensuring that scientific knowledge not only addresses technical challenges but also promotes an equitable distribution of agricultural knowledge and strengthens the institutional frameworks that facilitate its effective application in the agricultural sector.

4.3 Scientific production and keywords

Globally, the consistent presence of terms such as "technology adoption," "innovation" and "impact" highlights a continuous concern for implementing new solutions and evaluating their effects (Ekboir et al., 2009; Kumari et al., 2025). Furthermore, the strong correlation between "farmer" and "impact" in international studies and between "technology transfer" and "technology adoption" indicates the relevance of understanding how farmers interact with emerging technologies and their outcomes (Morepje et al., 2024; Sheikh et al., 2021). These global keyword trends underscore a focus on implementable and farmer-centric research, yet the local context reveals critical divergence from these international necessities.

In Peru, the keyword "impact" prevails, with peaks in 2020 and 2021, suggesting a primary focus on evaluating the results and effectiveness of interventions. Conversely, the minimal presence of "Development Country" and the absence of "extension service" are worrying indicators of a significant gap. This suggests less recorded activity and fewer studies related to the dissemination and transfer of technology to farmers. Crucially, Peruvian R&D suffers from disciplinary compartmentalization that isolates natural sciences from social sciences, limiting the holistic solutions adapted to the specific needs required by the heterogeneity of the Peruvian context. Thus, this lack of interdisciplinary attention to extension

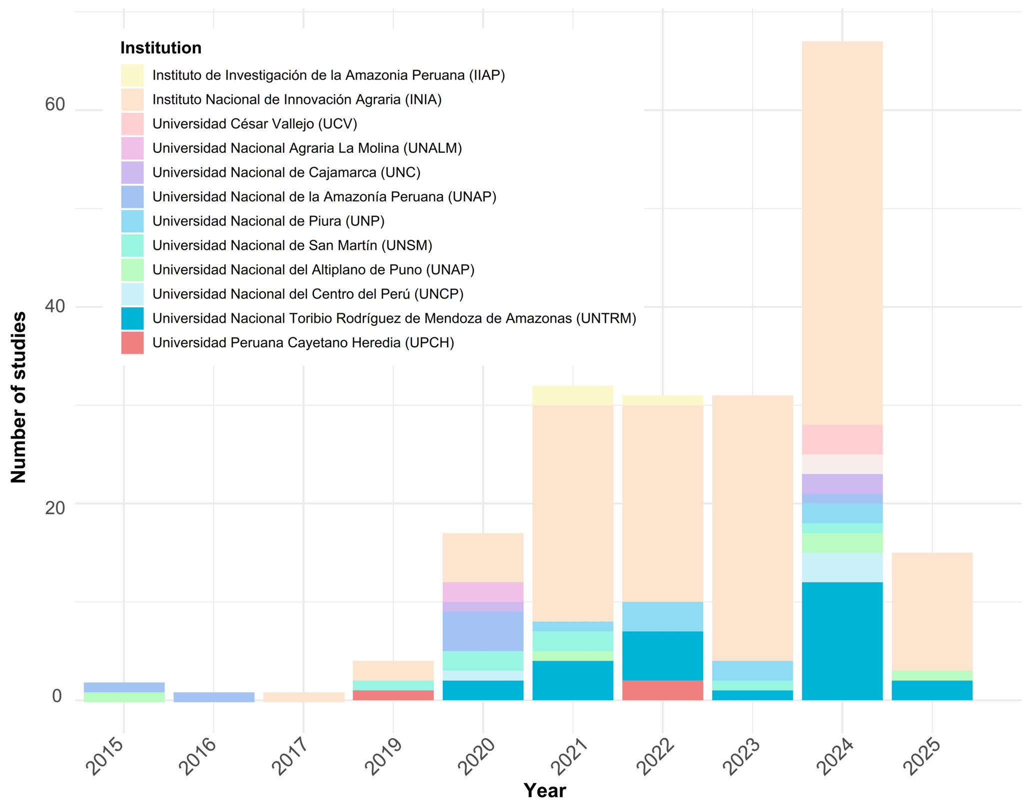

FIGURE 13
Amount of research published by the 12 entities with the highest scientific production in Peru between 2015 and 2025.

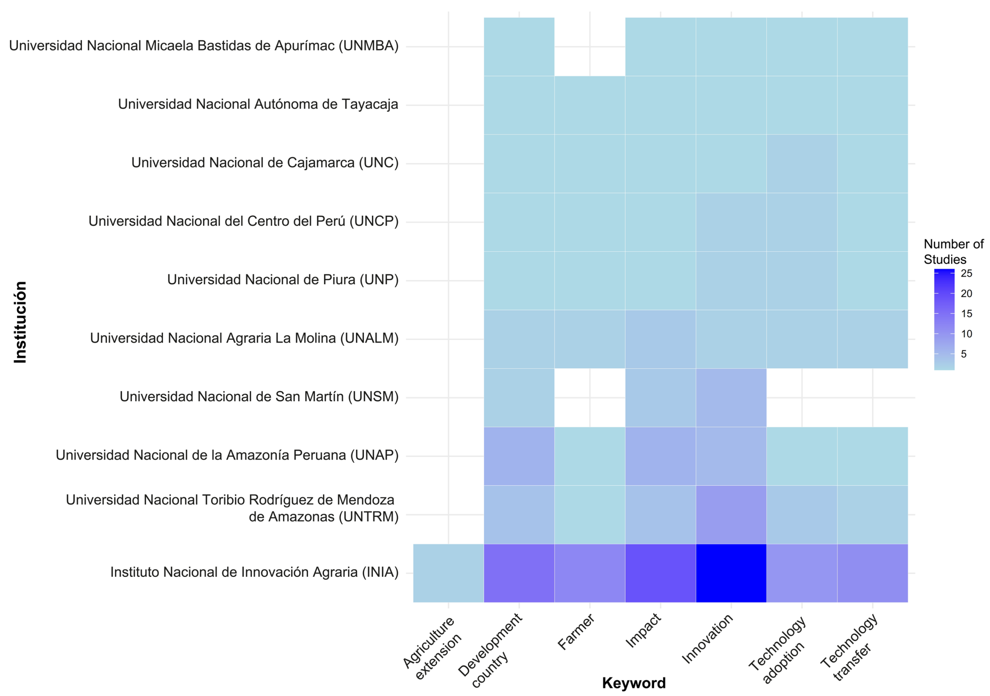

FIGURE 14
Heatmap of the number of publications in the 10 leading Peruvian institutions in relation to the keywords considered for this study.

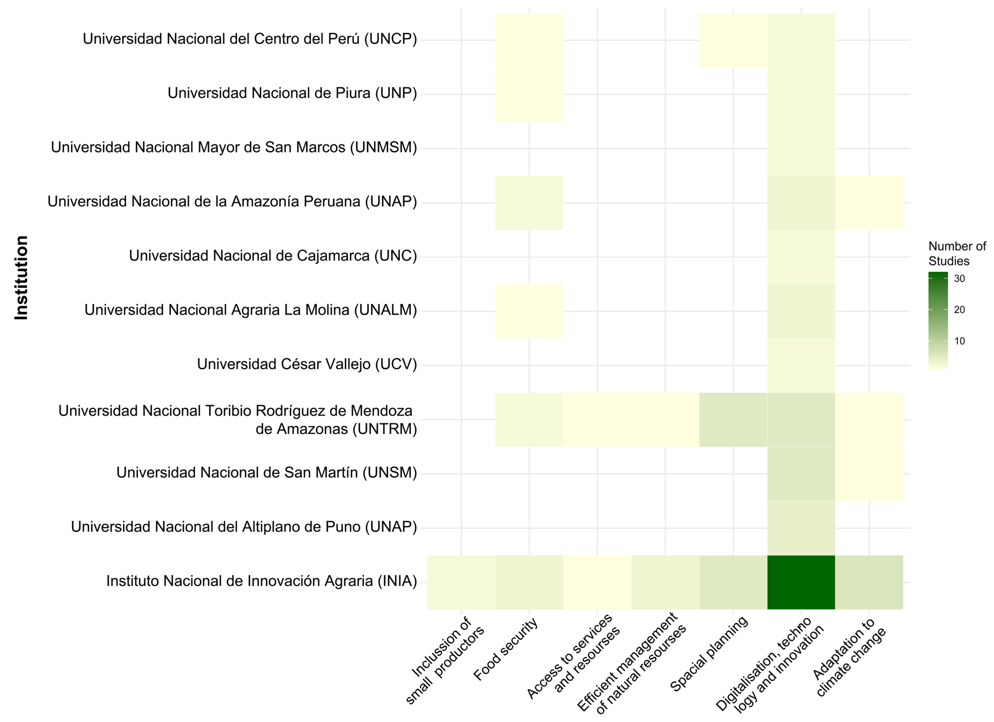

FIGURE 15
Heatmap of the number of publications in the top 10 Peruvian institutions in relation to the keywords considered for this study.

and support services for technology adoption underscores a crucial sector that needs more focus, funding, and documentation. To effectively bridge this gap and overcome disciplinary silos, Peruvian agricultural innovation must adopt an integrated, multi-stakeholder approach, such as the quadruple helix model (Azzarone et al., 2025; Schütz et al., 2019). This model, by formally incorporating academia, industry, government, and civil society (including farmer organizations), provides a framework to integrate scientific rigor (natural sciences) with social relevance and contextual adaptation (social sciences). Implementing the quadruple helix would solidify commitment, foster co-creation of knowledge, and ensure that scientific output is directly channeled through robust extension services to achieve concrete benefits for farmers.

4.4 Institutional actors and scientific production

An analysis of scientific output from 2015 to 2025 highlights the crucial role of institutions in agricultural research and extension. Globally, the significant increase in research disseminated by leading institutions, with a peak in 2023, confirms the growing investment and research capacity within the sector. Wageningen University & Research (WUR) distinguishes itself through its unique multidisciplinary approach and leadership in applied agricultural studies. This underscores the importance of translating scientific knowledge into actionable on-farm practices. Moreover, the consistent scientific output from universities in Africa and Asia demonstrates a burgeoning research capacity in developing regions, fostering a greater diversification of knowledge that reflects their diverse geographical contexts (Mason-D'Croz et al., 2019).

In Peru, Public Research Institutions (PRIs) such as the National Institute of Agrarian Innovation (INIA), Universidad Nacional de Piura (UNP), and Universidad Nacional Toribio Rodriguez de Mendoza (UNTRM) institutes have driven scientific production in recent years, aligning with the MIDAGRI Agrarian Development Plan 2021–2030. This focus on strategic themes is vital for ensuring that research addresses national needs and priorities (Abdenur et al., 2019). The emphasis on digitalization, technology, and innovation reflects a commitment to global trends in the agricultural sector, aiming to modernize farming practices and enhance productivity (Lowder et al., 2025). However, the critical lack of research on institutional governance and the effective inclusion of small-scale producers in Peruvian studies reveals a profound systematic gap. This limitation suggests that, despite that existing focus on technological investment and extension services, a persistent deficit remains in the effective implementation of technologies at the farm level. This implementation failure it is not simply attributes to funding constraints; rather, it indicates prioritization failure where institutional resources and research interests have favored technological outputs over resolving the fundamental structural and equity challenges that impede technology adoption.

The findings of this review highlight the necessity of balancing resource allocation in agricultural research and extension, both globally and nationally. While modernization and technological innovation are crucial, the current approach, which treats social, economic and governance dimension as secondary considerations, guarantees the limited impact of technological investments. It is imperative to promote strategic research that view the governance and inclusion deficits as the primary bottleneck to agricultural transformation. Only through such a radical re-prioritization can be holistic and effective modernization of the agricultural sector be achieved, ensuring that the benefits of research reach all stakeholders and are sustained over time by actively institutionalizing the participation of agricultural producers in the design and validation of knowledge.

4.5 Public policy framework and investment in agriculture

Agriculture in Peru stands at a critical juncture, facing significant structural and strategic challenges that constrain agrarian research and innovation. Despite the sector's vital socio-economic role contributing over 7% of Gross Domestic Product (GDP) and sustaining a substantial portion of the rural population the public policy framework remains fragmented, notably characterized by limited institutional coordination (The World Bank, 2021). Although MIDAGRI operates adscript institutions (e.g., Agro Mercado, ANA, INIA, SENASA, SERFOR) tasked with resource management, research, extension, and rural development, their roles are insufficiently integrated, leading to overlapping responsibilities and operational inefficiencies.

This fragmentation is exacerbated by the persistent underinvestment in agricultural research, which remains critically low at approximately 0.17% of agricultural GDP far below the Latin American average of 1.14% (The World Bank, 2021). Such limited funding not only constrains research capacity but also creates structural bottlenecks that hinder long-term scientific development. As noted by Wang et al. (2022), this financial deficit weakens progress toward key strategic objectives, particularly in governance, technological innovation, and equity. Moreover, the lack of a coherent policy framework that explicitly integrates equity, territorial diversity, and the country's exceptional agrobiodiversity further limits the potential for transformational change. As highlighted by Arotoma-Rojas et al. (2024), without a policy architecture capable of aligning scientific outputs with national priorities, research efforts remain isolated, reactive, and insufficiently translated into scalable interventions. Collectively, these weaknesses reveal not only a resource gap but also a deeper misalignment between research production, public policy, and the structural challenges facing the agricultural sector. Consequently, institutional strengthening, democratizing research opportunities, and fostering interdisciplinary cooperation are increasingly imperative within Perú's public policy frameworks.

A critical requiring immediate reform is the methodology of agriculture extension. The persisted predominance of hierarchical (top-down) transfer model present a systemic limitation that decapitalizes local knowledge and reduces technology to a standardized package, thereby frustrating open and adaptative innovation (co-creation). In this regard, coordinated efforts among PRIs, producer organizations, and MIDAGRI's sub-institutions must actively promote models where the producer is an active partner in applied research (farmer-lead innovation). This entails training for the use of technologies such as sensors and information platforms to allow farmers to validate, adapt and customize scientific practices to their own agroecological context.

Moreover, aligning investment decisions with key Sustainable Development Goals (SDGs) such as hunger eradication, gender equality, and climate resilience is essential. Greater emphasis on developing innovation ecosystems that integrate governance reforms, technological advancement, and social inclusion is necessary to enhance the sector's ability to address pressing challenges like climate adaptation, rural poverty, and food security (Hossain and Kashem, 2025). While Peru's agricultural sector benefits from a rich natural resource base and emerging market opportunities, addressing institutional fragmentation and chronic underinvestment is non-negotiable for realizing its full potential (Ge and Rios, 2025; Salmoral et al., 2020). Strategic, equitable, and well-coordinate policies, supported by strengthened institutional capacities, will catalyze a more inclusive, substantiable, and resilient development trajectory, contributing significantly to wider national development goals.

4.6 Lesson learning

The main lessons that can be drawn from this study are as follows: Sustained and strategic investment is the primary driver of scientific leadership. Without a robust and continuous financial commitment, it is challenging to compete or lead in knowledge generation. Institutional specialization in critical areas, such as agrarian extension exemplified by Wageningen University & Research (WUR), is essential for ensuring that research transcends the academic realm and translates into tangible, real-world impacts on the ground for that is must be adopting the quadruple helix model. Additionally, generating knowledge is insufficient; its effective dissemination and adoption are crucial (de Janvry and Sadoulet, 2020), which means directly involving producers not just as recipients but also as active participants in the innovation process (farmer-led innovation). Additionally, success hinges on addressing the specific agricultural complexities of each region in Peru. This approach mirrors positive innovation trends observed in Asian countries, where producer participation has been central to joint innovation efforts. Similarly, active decentralization and regional strengthening strategies are essential for addressing diverse agroecological specificities and local needs (Hellin, 2012; Morales, 2022). Finally, the persistent research gap in governance and institutionality suggests that, despite technological advancements, the political and structural frameworks that enable effective innovation often lag behind. The lack of attention to these aspects can limit the real impact and sustainability of scientific discoveries.

4.7 Strategic planning and long-term commitment

The strengthening of investment in agrarian R&D in developing countries is crucial for boosting agricultural research and development (Zougmoré et al., 2021). This fundamentally involves strategically allocating resources toward high-impact and nationally relevant areas, such as climate change adaptation, biotechnology applied to native crops, and the digitalization of agriculture (Barbosa, 2024). Furthermore, the decentralization and specialization of regional research must be supported by strengthening research centers, prioritizing regions with high agroecological potential and specific needs. Additionally, this also entails investment in infrastructure, equipment, and the development of local human capital (de Janvry and Sadoulet, 2020). However, persistent disparities in resource allocation, fragmentation among institutions, and short-term political cycles continue to limit the effectiveness of R&D initiatives. Without coordinated governance structures, stable financing mechanisms, and stronger linkages between research and policy, investments risk becoming isolated efforts rather than drivers of transformative agricultural innovation.

The fostering of strategic alliances and technology transfer is crucial for establishing and strengthening both international and national collaboration. In the international context, strategic collaborations with leading agrarian research institutions facilitate technology transfer via knowledge exchange (Nguyen-Viet et al., 2025). At the national scale, fostering cooperation among the academic, private, and governmental sectors ensures that research addresses market needs, leading to viable solutions. Furthermore, documentation and research on agricultural extension services should be an explicit priority, actively involving producers.

To close the research gap in agricultural governance, public policies, and institutional strengthening are needed. Investments in studies that analyze regulatory frameworks, the efficiency of institutions linked to agriculture, the participation of stakeholders in decision-making, and barriers to technological adoption should be made (Abdenur et al., 2019; Barbosa, 2024). Continuous documentation and analysis are crucial for fostering a conducive environment that sustains innovation and ensures an equitable distribution of benefits (Barbosa, 2024). Furthermore, topics such as gender equality and rural youth need to be consistently included in all research streams, with the recognition that they are cross-cutting and fundamental dimensions for equitable and sustainable long-term development (Kumari et al., 2025). These commitments, when coherently integrated and pursued with a long-term vision, will enable developing countries, such as Peru, to modernize their agricultural sector and consolidate their position as generators of relevant and impactful knowledge in the changing global context.

4.8 Challenges and futures researcher

Despite providing a systematic synthesis of global and national agricultural R&D and extension trends, this study faced key limitations, primarily stemming from the scarcity of peer-reviewed literature on extension services and technology transfer within the Peruvian context, necessitating the inclusion of gray literature, which introduces potential advocacy bias. A core challenge identified is the persistent disciplinary compartmentalization in Peruvian research, which hinders the development of holistic, context-specific solutions adapted to the nation's agroecological heterogeneity. Future research should prioritize a multi-pronged agenda: a) conducting primary, interdisciplinary case studies focusing on the effectiveness of farmer-led innovation models in specific Peruvian regions; b) generating rigorous quantitative data on the actual impact of decentralization policies on local research capacity and resource allocation; and c) developing and testing quadruple helix engagement frameworks to integrate governmental, academic, private, and farmer organizations, thereby solidifying institutional capacity and ensuring research output is aligned with both national policy and grassroots needs.

5 Conclusion

Owing to their strategic investments, the global agricultural research landscape, spearheaded by the United States and China, clearly emphasizes technological innovation and sustainability. This is evident in their prioritization of resource management and resilience to climate change. Moreover, within South America, Brazil stands out as a regional leader in R&D, attributed to its well-articulated model and commitment to producer-oriented innovation. This global overview presents a valuable opportunity for Peru. While Peruvian agricultural research has historically been centralized in Lima, the emergence of regional centers of excellence in Amazonas, Junín, and Puno indicates a promising path toward knowledge decentralization. To fully capitalize on this potential and effectively address the country's diverse agroclimatic conditions, promoting decentralized funding policies and fostering the creation of interregional agricultural research networks are crucial.

Moreover, technological incorporation within Peru's agricultural sector still faces significant gaps in research related to governance, the inclusion of small-scale producers, and the effective linkage among developed technologies and on-the-ground needs. Despite interventions from various institutions offering technical and training support, the absence of a consolidated database hinders the effective evaluation of the impact of these initiatives. To move toward just and sustainable agricultural modernization, an integrated approach is essential. This must include the systematic recording of interventions such as training sessions, modular courses, and technical assistance provided by the private sector, regional and local governments, and the communities themselves. Only through such comprehensive data collection will it be possible to measure the agricultural sector's growth accurately, which aligns with the directives set by the Ministry of Agrarian Development and Irrigation (MIDAGRI).

Thus, investment in R&D needs to be increased, and the entity responsible for knowledge transfer needs to be strengthened. Moreover, the national innovation agenda must prioritize the active participation of small-scale producers, ensuring that technological solutions are relevant, accessible, and adapted to their realities. Only through a long-term vision and an inclusive approach can an agricultural innovation system that promotes real impact, territorial resilience, and social equity in rural areas be constructed whether in Peru or any other region.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

YO: Investigation, Writing – review & editing, Software, Formal analysis, Methodology, Validation, Data curation, Conceptualization, Writing – original draft, Visualization. JC-L: Writing – original draft, Resources, Validation, Conceptualization, Project administration, Supervision, Writing – review & editing. YA-R: Investigation, Data curation, Validation, Writing – original draft, Writing – review & editing. BC-C: Data curation, Validation, Writing – original draft, Writing – review & editing, Investigation. MA-I: Validation, Data curation, Writing – original draft, Investigation, Writing – review & editing. JT-C: Investigation, Data curation, Writing – original draft, Writing – review & editing, Validation, Methodology. FF-Z: Writing – original draft, Investigation, Writing – review & editing, Data curation, Validation. LG-F: Formal analysis, Writing – original draft, Data curation, Visualization, Writing – review & editing, Software, Methodology, Investigation. VT-M: Validation, Resources, Writing – review & editing, Project administration, Conceptualization, Supervision, Visualization. JG: Conceptualization, Validation, Writing – review & editing, Funding acquisition, Resources, Visualization, Project administration. DT: Supervision, Investigation, Writing – review & editing, Writing – original draft, Data curation, Visualization, Validation, Methodology. MG: Visualization, Writing – original draft, Validation, Methodology, Investigation, Supervision, Data curation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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