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Trends and challenges in the evaluation of agricultural research impact: a systematic literature review

ABSTRACT – This work aimed to conduct a systematic literature review on the evaluation of agricultural research impact, seeking to answer the question: "What have been the predominant themes, methodologies, and trends of evaluation studies on the agricultural research impact over time?" In order to do so, a textual data analysis was applied using natural language processing (NLP) techniques, such as tokenization and topic modeling. The analysis of 239 studies from 1969 to 2022 identified some thematic groups (climate change and food security, technology adoption, challenges in developing countries, sustainable agricultural practices, and poverty reduction) and 73 methodologies (methodological approaches, methods, and techniques). An increasing thematic focus was also observed on sustainability, resource management, and social impacts. The use of multiple methodologies within the same study grew in the 2000s. Although quantitative approaches have been the most frequently used in those studies, the findings show an emerging balance between qualitative and quantitative approaches, as well as a growing adoption of mixed methods.

Index terms: agricultural sustainability, responsible research and innovation, responsible research assessment, natural language processing.

Tendências e desafios na avaliação de impacto da pesquisa agrícola: uma revisão sistemática da literatura

RESUMO – Este trabalho teve como objetivo fazer uma revisão sistemática da literatura sobre a avaliação de impacto da pesquisa agrícola, buscando responder à pergunta: "Quais têm sido os temas, metodologias e tendências predominantes nos estudos de avaliação de impacto da pesquisa agrícola ao longo do tempo?" Para tanto, aplicou-se uma análise de dados textuais, por meio de técnicas de processamento de linguagem natural (PLN), como "tokenização" e modelagem de tópicos. A análise de 239 estudos de 1969 a 2022 identificou alguns grupos temáticos (mudanças climáticas e segurança alimentar, adoção de tecnologia, desafios em países em desenvolvimento, práticas agrícolas sustentáveis e redução da pobreza) e 73 metodologias (abordagens metodológicas, métodos e técnicas). Observou-se também um foco temático crescente em sustentabilidade, gestão de recursos e impactos sociais. O uso de múltiplas metodologias dentro do mesmo estudo cresceu nos anos 2000. Embora as abordagens quantitativas tenham sido as mais frequentemente utilizadas, a pesquisa mostra um equilíbrio emergente entre abordagens qualitativas e quantitativas, bem como uma adoção crescente de métodos mistos.

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INTRODUCTION

Agricultural research plays a crucial role in the balancing of production with environmental sustainability and in addressing climate change (Chaney & Feenstra et al., 2007; Pretty & Bharucha, 2014; Rockström et al., 2017; Deboe, 2020; FAO, 2022). This balance requires innovative and responsible approaches, aligned with the paradigms of responsible research and innovation (RRI) and responsible research assessment (RRA). These paradigms elucidate the conduct of ethical, equitable, and socially relevant research, which is continuously assessed from a multidimensional perspective, including, among other aspects, its societal benefits (Felt, 2018; Schuijff & Dijkstra, 2020; Curry et al., 2022; Schönbrodt et al., 2022).

As a means of improvement, impact evaluation emerges as a crucial element for measuring the contributions of research activities in various aspects (Reed et al., 2021, 2022). These evaluations analyze the prospective, ongoing, or completed actions, seeking to determine the changes that can be attributed to a specific project, program, or research policy in different dimensions, such as economic, social, and environmental ones, among others (Spaapen, 2015; Almeida et al., 2016; Fabian et al., 2018; Gertler et al., 2018). Furthermore, impact evaluation in agricultural research, particularly within the public sector, has been gaining increasing significance, especially by justifying the relevance of agricultural research, supporting its improvement, and fostering organizational learning derived from the results of these evaluations (Patton & Horton, 2009; Blundo-Canto et al., 2019; Lee et al., 2020; Turner et al., 2022).

Currently, the demand for such evaluations has been intensified with the adoption of new public management principles[1], which, through performance-based funding guidelines, impose the need for periodic impact measurement, to show the anticipated or generated social value, as well as to guide the efficient allocation of resources (Gaunand et al., 2015). In this regard, a study focusing on the most explored themes, methodologies, and emerging trends can be particularly valuable in supporting researchers, evaluators, and managers who are interested in impact evaluations and who are actively engaged in conducting them.

Previous literature reviews, such as those by Weisshuhn et al. (2018), identify the most commonly studied dimensions in impact evaluations, as well as the predominant methods employed. Their classification of methods into two main categories – type I (conceptual, qualitative, and quantitative), and type II (review, framework development, survey, stochastic method, economic valuation, participatory evaluation, and case studies) – provides a useful overview. However, their analysis does not delve into specific techniques or approaches within these categories, nor does it offer a temporal perspective on the application of these methods.

Similarly, although literature reviews focused on specific themes exist, such as that by Deboe (2020), which explores "sustainability" in terms of agricultural policies, they lack a broader analysis of themes and topics investigated in research and development (R&D) impact evaluations. This highlights a gap in the literature for comprehensive, aggregated studies that address both thematic breadth and methodological detail, providing critical insights to advance the field. Specifically, there is a need for analyses of agricultural R&D impact evaluation that explore themes over time and methodologies

[1] New public management (NPM) represents a shift in public sector management practices, focusing on efficiency, effectiveness, and market-oriented approaches. It emerged as a response to criticisms of traditional bureaucratic administration, emphasizing the adoption of private sector techniques. The core principles of NPM include decentralization, performance measurement, results-driven management, and customer-focused service delivery, aiming to improve public service quality and accountability (Islam, 2015).

employed in their investigation. Identifying trends in these aspects – such as temporal patterns, emerging thematic focuses, or shifts in methodologies – represent an opportunity for further research and practice in evaluation.

To fill this gap, this work aimed to conduct a systematic literature review on agricultural research impact evaluation, seeking to answer the question: “What have been the predominant themes, methodologies, and trends of studies on the impact evaluation of agricultural research over time?” To this end, selection and screening methods for scientific studies were used, alongside unsupervised data analysis, with the application of natural language processing (NLP) techniques. Supporting the analysis, a literature review on impact evaluation in agriculture is presented, followed by the methodological procedures employed, results, discussion, and, finally, the concluding remarks.

LITERATURE REVIEW: IMPACT EVALUATION IN AGRICULTURAL RESEARCH

The history of impact evaluation in agriculture is complex and multifaceted. Although it is challenging to identify the very first study in this area, Evenson et al. (1979) acknowledge that this process has its roots in the 19th century, when the articulation between science and agricultural practice was already observed. The formalization of impact evaluation in agriculture is generally considered to have begun in the 1950s (Colinet, 2021), with the emergence of more systematic and methodological approaches to examine the effects of agricultural innovations (Evenson & Westphal, 1995; Evenson, 2001). This movement emerged from the need to quantify the impacts of technological innovations, especially in the context of the Green Revolution (Evenson & Gollin, 2003; Alene & Coulibaly, 2009; ACIAR, 2022; Campagnolla & Macêdo, 2022). During this period, there was a greater focus on developing quantitative methodologies, to establish cause-and-effect relationships, and on analyzing the economic impacts (costs and benefits) of agricultural interventions (Norton & Alwang, 2016).

Over time, these evaluations broadened their scope, shifting toward the measurement of the effects of interventions (such as actions, programs, public policies, and technologies) in different dimensions, such as environmental, economic, and social aspects, among others, with the goal of identifying quantifiable changes through indicators. Those impacts, which can be attributed to specific interventions, whether from public or private institutions (Cameron et al., 2016; Weisshuhn et al., 2018). According to Rogers (2003), measuring the reach of these impacts is closely tied to the adoption of agricultural research innovations. While this adoption-focused perspective has been subject to criticism, particularly for its occasional oversimplification of the pathways from adoption to impact, it is important to recognize that “adoption” is a necessary, though not always sufficient, condition for achieving the intended impacts. In other words, although adopting the innovation alone does not guarantee the accomplishment of desired impacts, it remains a critical step in the process of translating research into tangible benefits. In this context, adoption refers to the acceptance by an agent – particularly, but not exclusively, farmers – of an innovation (such as a new agricultural practice, technology, or other advancements) derived from research. Thus, adoption is an essential component for promoting impacts and is also used as an indicator for the impact evaluation of agricultural technologies (Avila et al., 2008).

The most employed methodologies to measure these impacts include a combination of observational and experimental techniques, such as controlled trials and qualitative surveys; and recent advances in methodologies like randomized controlled trials (RCTs) have enabled more rigorous assessments of agricultural interventions, becoming more common in the last two decades (Norton & Alwang, 2016). However, RCTs remain uncommon, due to challenges with control and treatment groups, ethical concerns about withholding beneficial interventions, and high costs. RCTs represent a unique experimental approach, randomly assigning interventions to participants, ensuring unbiased distribution, and enabling robust causal inferences (Norton & Alwang, 2016; Gertler et al., 2018).

Quasi experimental and nonexperimental approaches are also used to measure impacts of agricultural research, according to Norton & Alwang (2016). *Quasi* experimental approaches refer to nonrandom studies, in which a comparison group is chosen nonrandomly but still aims to control confounding variables (Gertler et al., 2018). Nonexperimental studies differ by not involving random allocation of interventions and often rely on observational data (Newcomer et al., 2015). Regarding the use of these approaches, Evenson et al. (2001) highlight the frequent use of experimental and *quasi* experimental methods in the context of agricultural R&D impact evaluation.

However, this perspective is challenged by studies that carried out a systematic review focused on understanding the most commonly used methodologies in agricultural impact evaluation. For instance, a study conducted by the Independent Evaluation Group of the World Bank, which analyzed studies from 2000 to 2009, found that experimental approaches were rare and appeared mostly after 2005 (Independent Evaluation Group, 2011). According to the authors, *quasi* experimental approaches occurred in 60% of the analyzed studies, from which techniques stood out, such as propensity score matching (PSM), difference-in-differences (DiD), instrumental variables (IV), and regression discontinuity (RD). Subsequently, nonexperimental approaches accounted for 34%, with techniques such as multivariate regressions and time series analysis were prominent.

Yet, in a literature review on agricultural R&D impact evaluation, Weisshuhn et al. (2018) noted that, although there is no universal preference for a specific method, qualitative approaches are particularly used for analyzing social impacts, while quantitative methods prevail in evaluating the economic impacts of research policies and programmes. Among the most common qualitative techniques in agricultural research impact evaluation, Weisshuhn et al. (2018)[2] identified interviews, questionnaires, expert surveys, and case studies. It can be observed that neither Weisshuhn et al. (2018) nor the Independent Evaluation Group (2011) provided a temporal perspective showing how themes and methods have been explored over time.

Reviews such as those by Deboe (2020) reported the impact of agricultural interventions concerning the themes of sustainability and agricultural productivity, identifying techniques such as technical efficiency (TE) and total factor productivity (TFP) as the most relevant ones within these two themes. While focused on a specific field (sustainability), Deboe's study does not address the temporal aspect nor specifically investigate agricultural R&D. Lee et al. (2020), however, systematically reviewed impact evaluation studies, to understand how these evaluations support the innovation process, but did not explore themes or trends. Therefore, a broader perspective, connecting themes and the most common methods in agricultural impact evaluation studies, is timely to support new agendas for agricultural R&D policies and actions.

More generally, studies that do not constitute literature reviews, such as those by Pingali (2012), help us to understand that, from the 1970s, these evaluations began to measure the environmental and social impacts of agricultural technologies. This does not mean that economic impacts were no

[2] The authors did not focus their analysis on the techniques themselves but rather on the types of methods used, presenting these techniques as the most frequent examples.

Cadernos de Ciência & Tecnologia, Brasília, v. 42, e27611, 2025
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longer investigated, but that new dimensions became relevant in the social and political contexts. According to Claudino & Talamini (2013) and Rodrigues & Rodrigues (2007), this fact led to the development and adoption of methodologies, such as life cycle analysis (LCA) and environmental impact assessment (EIA). Concerns about the environment and natural resources were intensified in the 1980s and 1990s, resulting in institutional initiatives to establish methods capable of capturing effects in different areas, such as the Environmental Impact Assessment System of Agricultural Technological Innovations (Ambitec-Agro), developed by the Embrapa (Rodrigues et al., 2003).

Faure et al. (2018) mention that the period from the 1990s to the 2000s was characterized by the adoption of qualitative methodologies and participatory evaluations. In addition, during this period, there was an emphasis on gender and equity issues (FAO, 2022). From 2010, the focus shifted to systemic approaches and trade-off analysis, aligned with the Sustainable Development Goals (SDGs), highlighting the need to balance the food production with natural resource conservation (FAO, 2000, 2011, 2022). Recently, there has been a move toward the use of information and communication technologies, such as big data, for public policy evaluations, as evidenced by Pinto & Bin (2024), reflecting a shift toward more innovative methods for impact evaluation in agriculture. Considering this scenario, the present study aimed to examine the methodologies and themes of impact evaluation over time, highlighting emerging trends in agricultural research impact evaluation, to contribute to the advancement of the field. In doing so, it supports researchers, evaluators, and policymakers in adopting more effective and socially relevant evaluation practices. The analysis will particularly focus on the perspectives of RRI and RRA, providing a foundation for new approaches in the development of agricultural public policies.

MATERIALS AND METHODS

The present study adopted a descriptive-exploratory approach (Cervo et al., 2006) based on the method of systematic review, applied to the unsupervised analysis[3] of textual data (Favero & Belfiore, 2017), in which two natural language programming (NLP)[4] techniques were used: tokenization and topic modeling (Silge & Robinson, 2017). Tokenization breaks down text into smaller units called "tokens". These tokens can be words, phrases, sentences, or other relevant linguistic elements (Silge & Robinson, 2017). Topic modeling is a technique aimed at identifying the topics, or subjects, present in a set of documents. Through the identification of keywords and expressions, it is possible to associate them with specific topics. This technique allows of the summarization of text collections, exploring content in more detail, and classifying documents based on their topics. When applying the technique, machine learning algorithms can uncover hidden topics in a collection of documents (Grün & Hornik, 2011). Next, the methodological procedures adopted at each stage of the analysis are presented.

Data source

For data collection, the Scopus and Web of Science databases were selected, due to their relevance, breadth, and quality, standing out as main sources of scientific information, as indicated by Harzing & Alakangas (2016) and Mongeon & Paul-Hus (2016).

A search string was structured based on the study of Weisshuhn et al. (2018) (Table 1);

[3] Unsupervised data analysis is an exploratory approach that does not use predefined categories or labels. Instead, it identifies hidden patterns and latent structures within the data. In the context of the present study, topic modeling is used to discover recurring themes in textual data without assuming specific categories.

[4] Natural language processing (NLP) is a field of artificial intelligence (AI) that focuses on the interaction between computers and human language. The goal of NLP is to enable computers to understand, interpret, manipulate, and generate text or speech in a similar manner to that of human communication.

this string incorporates broader descriptors related to impact evaluation, such as “adoption”, “effects”, “adaptation”, and “benefits”. This inclusion was deliberately made to ensure a comprehensive retrieval of studies, following the approach adopted by Weisshuhn et al. (2018). In April 2023, the search was performed in titles, abstracts, and keywords fields, to maximize the scope of the retrieved literature, using the Capes periodicals portal[5], and it did not limit temporal or geographical aspects in order to provide a broad perspective on the field.

Thus, 447 studies were recovered, which were subjected to treatments as described below.

Data preparation

For the preparation of the textual data, six steps were adopted – based on the recommendations by Silge & Robinson (2017) – described as follows.

1) Structuring of exclusion criteria, which are:
    a) Publications that do not correspond to the theme[6], by adopting an automatic analysis through regular expressions and manual verification, including reading the title and abstract.
    b) Studies without the “Abstract” variable filled.
    c) Studies published up to and including 2022.
2) Text transformation, removing and replacing unwanted characters.
3) Verification of duplicated studies within each database: Scopus and Web of Science, separately, and also between them.
4) Separation of words through tokens, bigrams, and removal of unwanted words (stopwords[7]) and stemming[8] of the data.
5) Creation of a frequency matrix to categorize the “stems” and associate

Table 1. Search terms and results presented in databases.

Database	String	Amount
Scopus	(TITLE (agricult* AND (research* OR *scien* OR "R&D" OR innovati*) AND (impact* OR assess* OR evaluat* OR criteria* OR benefit* OR adoption* OR adaptation*))) AND (TITLE-ABS-KEY (agricult* W/1 (research* OR *scien* OR "R&D" OR innovati*) AND (research* OR *scien* OR "R&D" OR innovati*) W/2 (impact* OR assess* OR evaluat* OR criteria* OR benefit* OR adoption* OR adaptation* OR outcome*)))	191
Web of Science	TI = (agricult* AND (research* OR *scien* OR "R&D" OR innovati*) AND (impact* OR assess* OR evaluat* OR criteria* OR benefit* OR adoption* OR adaptation*)) AND TS = (agricult* NEAR/1 (research* OR *scien* OR "R&D" OR innovati*) AND (research* OR *scien* OR "R&D" OR innovati*) NEAR/2 (impact* OR assess* OR evaluat* OR criteria* OR benefit* OR adoption* OR adaptation*))	256

[5] Brazilian initiative to provide access to a set of scientific information in higher education public institutions. Available at: <https://www.periodicos.capes.gov.br/>.

[6] Verification of suitability for the topic of interest using regular expressions in the variables, such as “title” and “abstract”.

[7] Stopwords are very common and frequently used words in language, such as articles, prepositions ,and pronouns, which generally do not contribute to the specific meaning or context of a text (Silge & Robinson, 2017).

[8] Stemization is a process of reducing words to their basic or root form, called “stem”. This is done by removing suffixes and prefixes from words, keeping only the central common part. Stemization is used to group words that have the same root (even if they have morphological variations), which facilitates the analysis and comparison of related words (Silge & Robinson, 2017).

Cadernos de Ciência & Tecnologia, Brasília, v. 42, e27611, 2025
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them with their respective occurrence frequencies in the texts, allowing of inferences about proximity, distance, synonyms, and related terms.

6) Creation of a corpus[9] for topic extraction from the variables "title, abstract, keyword, and author keyword".

Identification of themes

To identify explored themes in agricultural R&D, a combination of tokenization was employed through the bigram analysis and topic modeling. Bigram analysis was used to detect frequent occurrences of pairs of words, providing an initial insight into the thematic content of the publications. Subsequently, topic modeling was applied to group the publications based on thematic similarities for the leveraging of machine learning to uncover latent structures. These two techniques complement each other, adding robustness to the thematic analysis. Bigram analysis shows pairs of words with the highest frequency, offering a view of prominent co-occurring terms across the corpus. Topic modeling, in turn, allows of the analysis of how these frequently occurring terms are distributed, according to their semantic similarities. This method makes it possible to observe that a single bigram may be associated with different thematic topics, thus highlighting the interconnectedness and complexity of the themes.

Additionally, Zipf's theory (Zipf, 1949) was incorporated, alongside the bigram analysis (Silge & Robinson, 2017), to account for the frequency of word pairs in the studied corpus. Furthermore, topic modeling was conducted using the latent Dirichlet allocation (LDA) method (Grün & Hornik, 2011; Silge & Robinson, 2017), establishing six topics[10] for each theme. The number of topics was determined using the Elbow method (Favero & Belfiore, 2017), which assesses the data variance in relation to the number of clusters most suitable for the sample. In addition, a coherence test[11] of the topics was performed (Röder et al., 2015), to validate the quality and interpretability of the topics obtained.

Procedure for identifying trend patterns

To identify thematic trends and methodologies over the coming years (until 2030), the following procedure was used:

1) Extraction of bigrams that represent relevant themes in the evaluation of agricultural research, based on their occurrence in the decade.
2) Calculation of the cumulative frequency of each bigram across the analyzed decade[12], covering all available years in the sample.
3) Normalization of the cumulative frequency of each bigram by the total number of years analyzed over the past two decades.
4) Projection of growth trends, based on the assumption that the observed annual growth pattern for 2020-2022 will continue until 2030.
5) Enumeration of the themes with the highest annual average occurrence, and identification of those that showed growth over the analyzed period.

[9] In the field of computational linguistics and natural language processing, a corpus is a collection of written or spoken texts that are used for linguistic research and analysis; a corpus can include anything from books and magazines to transcripts of conversations, speeches, tweets, etc. (Silge & Robinson, 2017).

[10] In the present study, group and topic are treated as synonyms when it comes to topic modeling.

[11] The topic coherence test is a useful tool in the evaluation and adjustment of topic models, allowing of the identification of the quality of the generated topics and the optimization of the model parameters, to obtain better results (Röder et al., 2015).

[12] For the current decade (2020-2022), the frequency was divided by three to account for the partial timeframe.

Identification of methodologies

To identify the techniques and methodologies adopted in the sample studies, the following procedures were used:

1) First, an attempt was made to identify methodologies through trigrams, via frequency analysis and manual validation[13].
2) Simultaneously, additional techniques and methods were incorporated, culminating in a dictionary of 103 techniques (Norton & Alwang, 2016; Gertler et al., 2018; Weisshuhn et al., 2018; Arruda, 2021; Meneses & Pinto 2021; Reed et al., 2021, 2022).
3) In the organization, the methods and techniques were classified as conceptual, qualitative, or quantitative, according to the following definitions, based on Weisshuhn et al. (2018):

Conceptual

These involve the development of frameworks or concepts to measure the impacts of agricultural research. Such approaches focus on building theoretical models, such as tracing the pathways of innovation or identifying barriers and factors that support impact generation.

Qualitative

These use descriptive data, typically collected through interviews, questionnaires, expert surveys, or choice experiments. These methods are useful for capturing stakeholders" perceptions, attitudes, and preferences regarding new technologies, including their willingness to pay or preference for adoption measures.

Quantitative

These are based on numerical measurements conducted in a standardized manner. Data are on a metric scale and are often used for modeling, such as regression analyses, stochastic methods, or econometric approaches like cost-benefit or cost-effectiveness analysis. They are frequently applied to measure economic impacts.

4) Development of an algorithm to verify the methods used in the studies of the sample, considering the dictionary created. This verification was based on the creation of a combined variable from the metadata: title, abstract, keywords, and author keywords.
5) Categorization of methodologies into three categories: analysis, data collection, and design. "Analysis" include approaches, methods, and techniques used in impact studies to examine phenomena, whether through detailed exploration or technical evaluation. "Data collection" refers to the instruments and tools employed to gather data. "Design" pertains to the frameworks or strategies used to structure and plan impact evaluations.

It is important to highlight that the developed dictionary encompasses methodological approaches, methods, and techniques. Methodological approaches relate to broad ways of conducting the research, providing general guidance on how to structure the research process, such as participatory approaches or experimental design. Methods refer to the general procedures employed in impact evaluation, such as case studies or econometric analyses, whereas techniques are specific tools used within these methods, such as interviews, questionnaires, or linear regression. To summarize the procedures described in the methodology section, an overview is provided for all the steps involved in the methodological process (Figure 1).

[13] Considering authors' knowledge.

Cadernos de Ciência & Tecnologia, Brasília, v. 42, e27611, 2025
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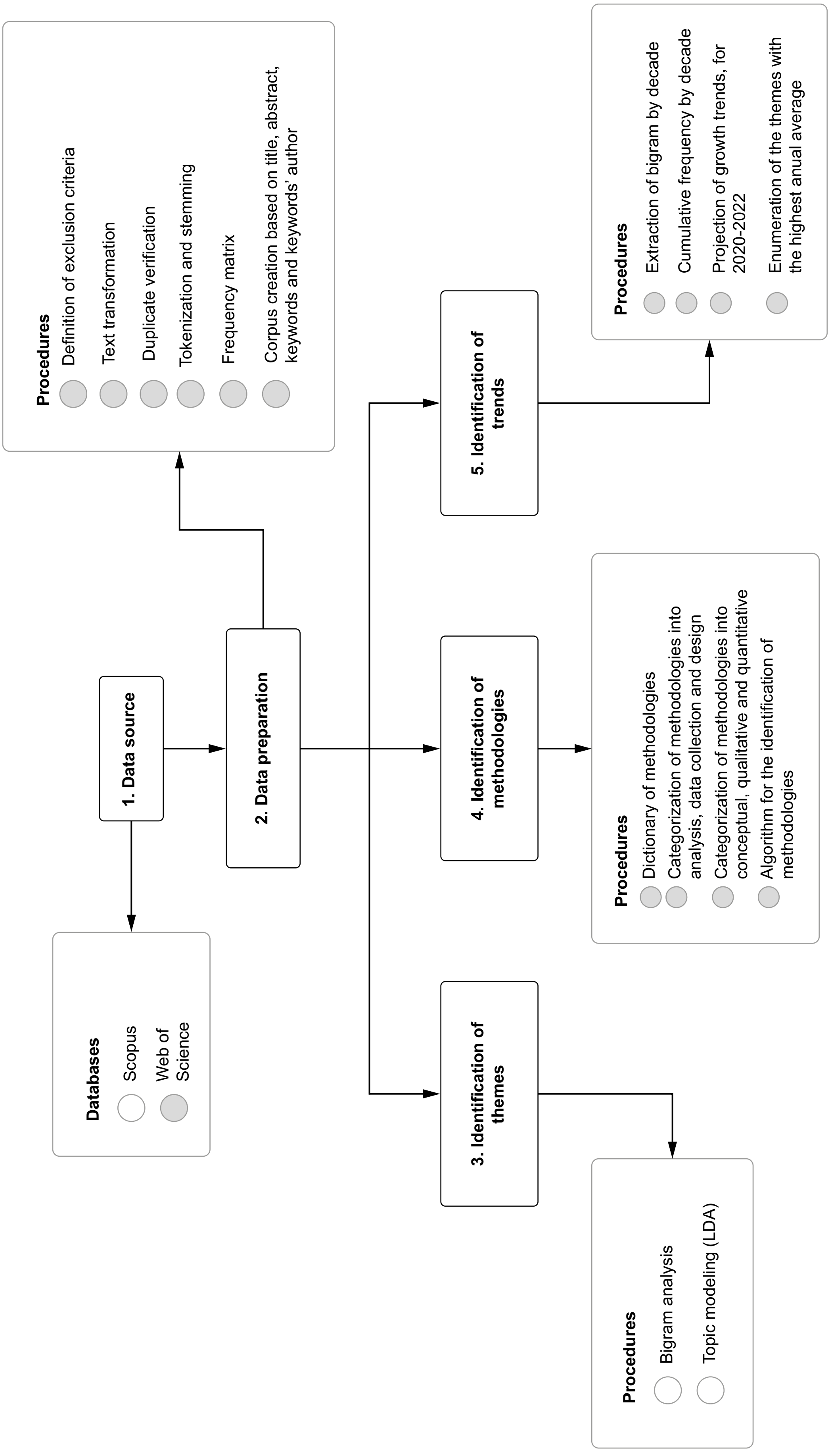

Figure 1. Methodological workflow applied to the study.

Tools used

The R programming language (version 4.1.2 - 2021-11-01) and the RStudio work environment (version 2021.9.0.351) were used in this study. For identifying duplicates and cleaning the sample, the following packages were employed: “stopwords”, “tidyverse”, “dplyr”, “stringi”, “readr”, “writexl”, “readxl”, “textplot”, “XML”, and “readxl”. For tokenization and topic modeling, the packages “textrank”, “tibble”, “gt”, “topicmodels”, “tm”, “textplot”, “caret”, “tidyr”, “quanteda”, “stringr”, “NLP”, “curl”, “tidytext”, “tm”, “cluster”, “factoextra”, and “knitr” were used. For data visualization, the packages used were “owlcarouselR”, “htmltools”, “slickR”, “gt”, “ggplot2”, “quanteda”, “stringr”, “curl”, “tidytext”, “wordcloud”, “SnowballC”, “RColorBrewer”, “wordcloud2”, “gridExtra”, “plotly”, “ggwordcloud”, “webshot2”, and “htmlwidgets”.

The data analysis and visualization functionalities of Excel (online version - Microsoft 365), Google Sheets, and Tableau (version 20232.24.0115.0353) were also employed to complement the process. The raw data and algorithms used in this study are available for public access in GitHub repository (Maciel, 2024a). The dictionary of methodologies created for the research is also available for consultation and download (Maciel, 2024b).

Findings

A total of 239 publications were selected (Table 2), sourced from the Scopus (176) and Web of Science (63) databases, spanning 53 years (1969 to 2022). The first identified study dates back to 1969, titled “Evaluation of Public Research Programs in Agriculture,” authored by Andarawewa (1969). It is an *ex ante* evaluation of the management of public resources allocated to agricultural research, emphasizing the need to improve and formalize this management.

Overall, the majority of these publications are journal articles, totaling 183, followed by 32 conference papers or reviews, 14 literature reviews, 7 book chapters, 2 books, and 1 note. Among these sources, the journals that most frequently served as publication platforms were the following ones: “Agricultural Systems” (14 occurrences); “Food Policy” (8), “Agricultural Economics”, “Outlook on Agriculture”, and “Scientometrics” (6); “Australian Journal

Table 2. Growth of studies on impact evaluation of agricultural R&D per decade.

Item	1960	1970	1980	1990	2000	2010	2020	Total
Database								
Scopus	1	6	10	12	37	70	40	176
Web of Science	0	0	0	6	10	34	13	63
Document type								
Article/journal	1	5	10	16	36	71	44	183
Conference Paper/review	0	0	0	2	4	21	5	32
Book	0	0	0	0	0	1	1	2
Book chapter	0	0	0	0	3	2	2	7
Note	0	0	0	0	1	0	0	1
Review	0	1	0	0	2	9	2	14
Average of publication/year	0.1	0.6	1.0	1.8	4.7	10.4	5.3	4.5
Average of authors by publication	1	1.3	1.7	2	3.1	3.8	4	3.4
Amount of sources	1	6	9	12	29	85	49	169
Amount of publications	1	6	10	18	47	104	53	239

Cadernos de Ciência & Tecnologia, Brasília, v. 42, e27611, 2025
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of Agricultural and Resource Economics", "Experimental Agriculture", "Research Evaluation", and "Research Policy" (5). The annual average number of publications was 4.5, and each publication had an average of 3.4 authors. Although the 2020s decade is not yet complete, it is evident that both collaboration and the number of sources have systematically increased over the decades. The growth in the number of publications by decade follows an upward trend, starting with just one in the 1960s, reaching 53 in the 2020s, which is a trend that is still ongoing.

Identified themes

As detailed in the methodology section, two techniques were applied – the bigram analysis and the topic modeling – to identify relevant themes in the studied topic. The results of the bigram analysis showed ten recurring bigrams (Table 3). These bigrams transcend specific thematic boundaries and reflect issues that are widespread across different contexts. Their repeated presence in various study contexts and publication groups suggests that they represent common concerns which are transversal to multiple research themes. This overlap underscores the importance of the issues they represent and their connection across diverse fields of knowledge.

Following the bigram analysis, we applied topic modeling to group publications by thematic similarity, confirming and expanding upon the frequent themes highlighted by the bigrams. The topic modeling identified six distinct groups, each one representing a coherent thematic topic (Table 4). This modeling process reinforces the themes suggested by the bigrams and provides a broader context to interpret the findings. Each group is summarized in the column "topic" of Table 4, which includes the group classification, the number of studies per group, the main subjects addressed, and the countries with the greatest number of studies[14].

In the first group, classified as "Agricultural economics and development", 49 studies were identified. They cover subjects such as economic efficiency, economic growth, investments and returns, regional development, agricultural production and productivity, etc. Topics in this group (green) began to be discussed in the 1970s, with a 100% increase in the 1980s (Figure 2). From the 1990s to 2010, there was an average growth of 78% every decade. The 2020s show signs of growth for the group, indicating an increase of 0.2 publications per year in comparison with the previous decade. The study by Chandio et al. (2022) is an example of a publication in this group. It investigates the impact of R&D

Table 3. The highest frequency bigrams in the evaluation of agricultural research impact.

Bigram	1960	1970	1980	1990	2000	2010	2020	Total
Climate change / climate issues	0	0	0	0	13	31	16	60
Food security / food insecurity	0	0	0	0	5	19	19	43
Developing countries / developing world	0	1	3	3	11	13	11	42
Technology adoption	0	0	0	5	0	18	12	35
Smallholder farmers	0	0	0	0	0	15	19	34
Poverty reduction	0	0	0	0	17	4	3	24
Technology transfer	0	0	0	0	0	10	8	18
Sustainable development	0	0	0	0	0	11	6	17
Natural resources	0	0	0	0	5	7	0	12
Productivity growth	0	0	0	0	5	6	0	11

[14] Measure of expressiveness attributed by the number of countries present in the affiliations of each publication.

Table 4. List of main topics in agricultural research impact studies.

Topic	Group classification	Number of studies	Main subjects	Countries
1	Agricultural economics and development	49	Economic efficiency, economic growth, investments and returns, public policies and governance, regional development, agricultural production and productivity, research and technological development, improvement of production processes sector.	United States, Australia, United Kingdom, China, Netherlands, Pakistan, Italy
2	Technological innovation and performance	37	Technology and innovation, scientific development, quality assurance, performance evaluation, performance indices, information technology, rural development, key performance indicators.	China, Thailand, Indonesia, India, Italy, Mexico, Brazil, Russia, Slovenia, Australia, Japan, United States, Malaysia
3	Food security and climate change	33	Climate change, food security, management, adaptation, conservation, soil, production, conditions, gender, water.	United States, United Kingdom, Australia, Canada, South Africa, Netherlands, Germany, France, Zimbabwe, Colombia; Denmark, Mexico, Ethiopia, Japan, Philippines
4	Sustainable development and resource management	31	Global development, environmental management, agricultural poverty, decision making, natural resources, global information, resource allocation, recent decisions, economics and goals.	United States, Australia, Italy, Canada, Niger, Greece, France, Germany
5	Social impacts and institutional transformations in agricultural research	47	Sustainable development, learning process, participatory approach, social knowledge, institutional structure, organizational development, collaborative work, organizational learning, institutional capacity.	Netherlands, France, United Kingdom, Brazil, Canada
6	Adoption of sustainable agricultural technologies and practices	42	Adoption of sustainable practices, smallholder farmers, innovative agricultural technologies, crop varieties, dissemination of good practices, factors influencing adoption, impact of technology adoption, improvement of agricultural income, local knowledge and perceptions, agricultural product market.	United States, Netherlands, Germany, Niger, Nigeria, France, Turkey, Italy, Ghan

Cadernos de Ciência & Tecnologia, Brasília, v. 42, e27611, 2025
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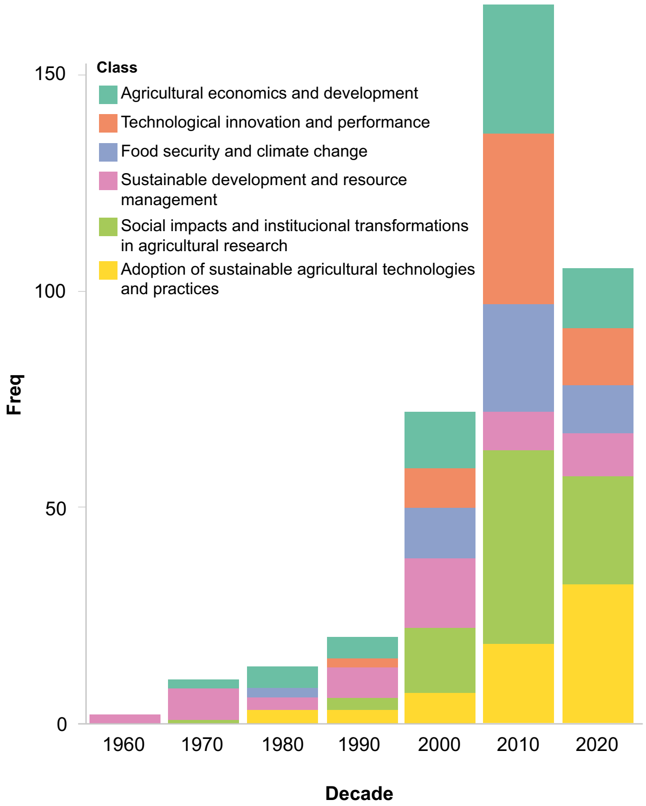

Figure 2. Distribution of classes by decades.

investment on agricultural crop production, specifically on grains in China, examining economic factors such as agricultural credit and environmental factors like CO_2 emissions and their influence on grain production, emphasizing food security and poverty reduction. Sorghum (Mills, 1997; Isinika, 2007) and barley (Petersen et al., 2002) emerge as crops[15] of interest in investigations in this class. The countries[16] with the highest number of publications for this group, in order of occurrence, were the United States, Australia, the United Kingdom, China, the Netherlands, Pakistan, and Italy.

The second group, "Technological innovation and performance" (orange), encompasses 37 studies related to technology and innovation, scientific development, quality assurance, information technology, rural development, key performance indicators, growth and performance improvement, technology transfer, ecology and environmental studies, technological capacity and readiness, as well as regional economy. There is no evidence of work in this class until the 1990s. Since then, interest in the class has increased considerably, reaching a peak of 633% in the 2010s. The 2020s provide evidence of an annual increase of 50%. Corn (Bellon et al., 2005) and sugarcane (Phisanbut et al., 2020) stand out in the investigations of this class. Regarding countries, China, Thailand, Indonesia, India, Italy, Mexico, Brazil, Russia, Slovenia, Australia, Japan, and the United States have the highest occurrence.

The "Food security and climate change (purple)" group consists of 33 studies exploring themes such as climate change, food security, management, adaptation, conservation, soil, production, conditions, gender issues, and water. This topic began to be discussed in the 1980s, but it did not register studies in the following decade. However, since the 2000s, interest has surged by 500%. The 2010s saw an additional growth of 216%, and the 2020s showed a trend for an annual growth of 28%. It is noteworthy that the theme related to gender issues only appears in the 2010s and 2020s, associated with food security, adoption of agricultural practices, and local conditions in agriculture, especially regarding innovation and tackling climate change (Smithers & Blay-Palmer, 2001; Bramley, 2009; Maredia & Raitzer, 2012; Makate et al., 2019; Widmer & Costa, 2021; Lopez et al., 2022; McGuire et al., 2022). Crops like wheat (Widmer & Costa, 2021), sugarcane (Bramley, 2009), soy (Smithers & Blay-Palmer, 2001), corn (Makate et al., 2019), and rice (Maredia & Raitzer, 2012) were highlighted in the context of this category.

The fourth group, titled "Sustainable development and resource management" (pink), includes 31 publications dealing with global development, environmental management, agricultural poverty, among others. It began in the 1960s and saw a 200% increase in the

[15] To identify crops, the 10 most relevant crops for global nutrition were used as references according to Ray et al. (2022).

[16] The presence of more than five countries indicates a tie for positions up to the fifth place.

1970s. After a drop in the 1980s, interest grew consistently in the following decades, reaching a peak of 80% in the 2000s. The 2010s brought a slight reduction compared to 2000, which is offset by the 2020s, indicating a possible annual increase of 122% in the number of studies. The report by Walker (2000) is an example of a study within this group, which discusses expectations regarding the documentation of the impact of agricultural research on poverty in ex post case studies. The study focuses on the role of agricultural research in poverty reduction, particularly in justifying investments in the public and international sectors. It is based on the experience of the International Potato Center (CIP) and highlights successful cases related to the development and implementation of improved technologies for potato and sweet potato. Besides these crops, cassava is also associated with this class, as shown in the work by Pemsl et al. (2022).

The fifth group, "Social impacts and institutional transformations in agricultural research" (light green), consists of 47 works exploring issues related to sustainable development, learning processes, participatory approaches, social knowledge, among others. Studies in this class began in the 1970s, with 100% increase in the 1980s. Between 1990 and 2000, interest skyrocketed, reaching 250% average. The 2010s experienced a growth of 75%, and for the 2020s there is an increment of 58.7%. Gava et al. (2020) work is an example of this class, in which life cycle analyses are used to measure and monitor environmental production processes, and suggest improvements to agricultural policies within the scope of research. It directly mentions SDGs 2 and 15. The most frequent countries in this group are the Netherlands, France, the United Kingdom, Brazil, and Canada.

Lastly, "Adoption of Sustainable Agricultural Technologies and Practices" (yellow) comprises 42 publications that deal with the adoption of sustainable practices, smallholder farmers, innovative agricultural technologies, crop varieties, dissemination of good practices, factors influencing adoption, the impact of technology adoption, and improvement of agricultural income, in addition to local knowledge and farmers' perceptions. This category did not receive much attention until the 1980s. There was a modest growth in the 1990s, followed by a significant jump in the 2000s, and additional growth in the 2010s. The 2020s show a trend toward an annual increase of 233%. In this class, crops such as rice (Mwaseba et al., 2006) , wheat (Ventorino et al., 2012; Mazid et al., 2015; Bouzid et al., 2020) , yam (Beckford, 2009; Soro et al., 2010; Omotesho et al., 2020) , corn (Doss & Morris, 2000; Ventorino et al., 2012) , and potato (Bouzid et al., 2020) stand out. The most frequent countries in this group are the United States, the Netherlands, Germany, Niger, Nigeria, France, Turkey, Italy, and Ghana.

Thematic trends

All groups show potential for significant growth until 2030 (Figure 3). The categories "adoption of sustainable agricultural technologies and practices", "sustainable development and resource management", and "social impacts and institutional transformations in agricultural research" are expected to experience the most pronounced increases, with respective growth rates of 233%, 122%, and 59%. The category "technological innovation and performance" shows moderate growth (51%), while "food security and climate change" and "agricultural economics and development" exhibit more stable trends, with 22% and 11% growth, respectively.

Associated bigrams, such as "climate change," "food security," "technology transfer," "smallholder farmers," and "developing countries," underscore their cross-cutting relevance across all groups.

Emerging bigrams include the following ones:

Cadernos de Ciência & Tecnologia, Brasília, v. 42, e27611, 2025
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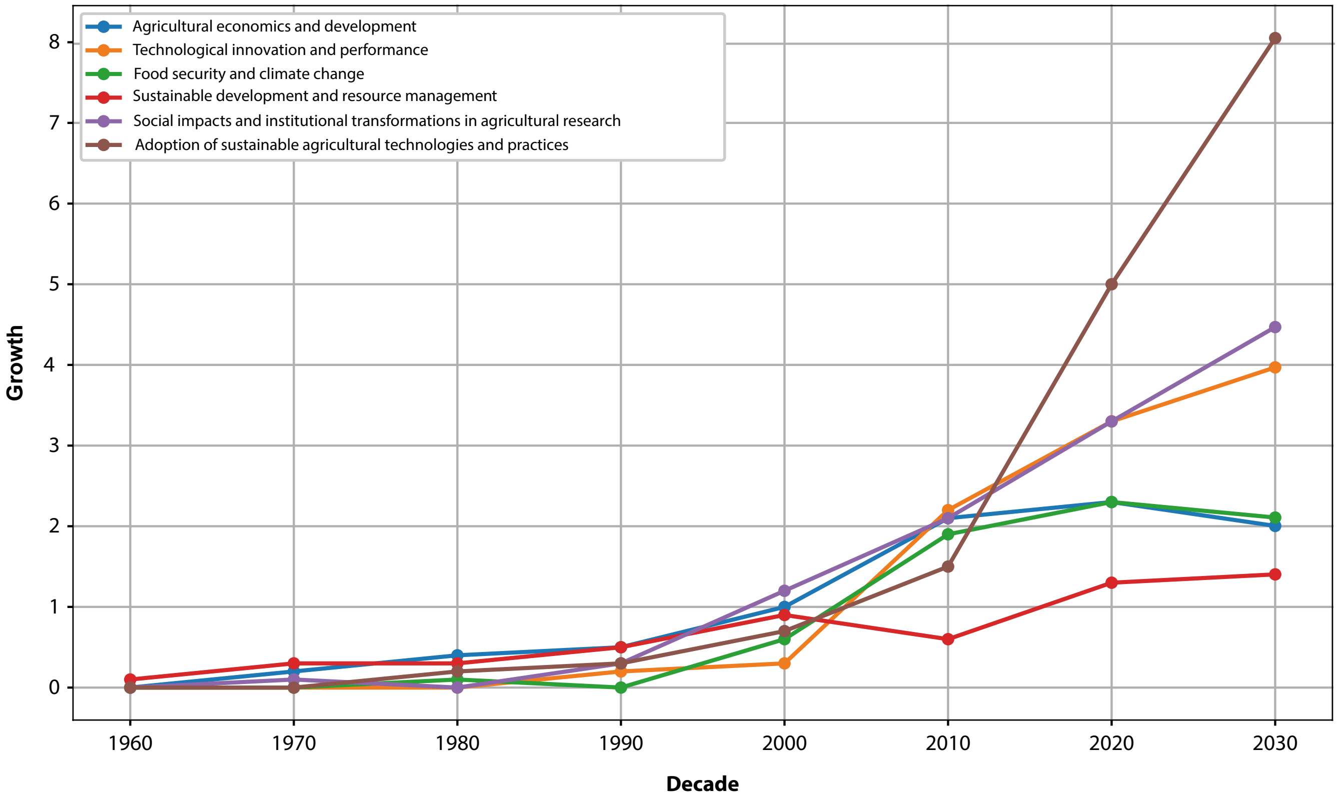

Figure 3. Trend patterns in the evaluation of agricultural research.

- "Technology readiness," linked to the technology readiness level (TRL).
- "Public extension," emphasizing rural technical assistance.
- "Farmers´ perception," highlighting producers´ engagement.
- "Gender considerations," addressing equity and inclusion.
- "Ecological environment," reflecting interactions between agriculture and ecosystems.
- "Sustainable development goals," aligned with commitments to the SDGs.
- "Internet of things (IoT)," "smart agriculture;" and "young farmers," focusing on the next generation of producers.

There is a stronger emphasis on the evaluation of "adoption of sustainable agricultural technologies and practices," supported by bigrams such as "public extension" and "farmers' perception." Similarly, "sustainable development and resource management" emerges as a priority, linked to bigrams like "gender considerations," "ecological environment," and "development goals." In contrast, "agricultural economics and development" shows more stable growth, reflecting a gradual evolution in this area.

Identified methodologies

A total of 73 distinct approaches, methods, and techniques were identified, corresponding to 70% of the created dictionary and were categorized into: "analysis," "data collection," and "design." The typology proposed by Weisshuhn et al. (2018)[17] was also applied, showing that the vast majority of studies utilize quantitative perspectives, particularly in the "analysis" category, with 42 incidences. However,

[17] The typologies used in this work are defined as follows: "conceptual" involves the development of theoretical frameworks; "qualitative" encompasses the use of nonnumerical data, such as texts and interviews, to explore perceptions; and "quantitative" refers to the analysis of numeric data to measure impacts. The classification was determined based on the analysis of the methodologies, as there are no specific sources categorizing them according to this typology.

"qualitative" and "conceptual" typologies displayed a more balanced distribution across the three categories, indicating a more diversified approach (Table 5). Efforts were also made to identify the works in relation to the type of evaluation design, whether experimental, nonexperimental, *or quasi* experimental, as outlined in the research conducted by the World Bank team (Independent Evaluation Group, 2011).

Regarding the application of techniques, the majority of studies – 152 in total – employed only one methodology. In contrast, 59 publications used two different methodologies, while a smaller group of studies, ranging from 9 to 2, used between three and seven methodologies, indicating a less common trend of combining multiple techniques within a single research. The distribution of the number of methodologies per publication by decade is presented together with the number of unique methodologies, the percentage growth of methodologies over time, and the percentage of each methodology in relation to the total number cataloged in the constructed dictionary (Table 6).

The use of only one methodology was predominant in the 1960s, but there was a considerable increase in the diversity and number of methodologies used in the following decades. From the 2000s onwards, not only the number of methodologies used increase, but also the combination of methodologies augmented

Table 5. List of methodologies by categories and typologies.

Design	Category	Typology	Number of methods
Experimental	Analysis	Quantitative	2
	Design		1
Nonexperimental	Analysis	Conceptual	9
		Qualitative	8
		Quantitative	34
	Analysis/data collection	Conceptual	1
		Qualitative	2
	Analysis/design	Qualitative	1
	Data collection	Qualitative	3
	Design	Conceptual	5
		Qualitative	1
Quasi experimental	Analysis	Quantitative	6

Table 6. Number of methodologies applied per decade.

Decade	Number of methodologies x number of publications							Total studies	Unique methodologies	Growth (%)	Percent of dictionary
	1	2	3	4	5	6	7				
1960		1						1	1	0	0.93
1970	4	1		1				6	7	600	6.54
1980	7	3						10	12	71.4	11.21
1990	17		1					18	16	33.3	14.95
2000	33	10	1	1	1		1	47	31	93.8	28.97
2010	67	24	5	5	2		1	104	60	93.5	56.07
2020	24	20	2	2	2	3		53	46	-23.3	42.99

Cadernos de Ciência & Tecnologia, Brasília, v. 42, e27611, 2025
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within the same study. The peak of 93.5% growth percentage observed in 2010, and the use of 56% of the total methodologies present in the dictionary, reflect a period of intense application and methodological diversification. In the distribution analysis of methodological typologies by decades and groups, it is noted that over the decades, there was a trend of transitioning from predominantly quantitative approaches to a more dynamic balance between “conceptual”, “qualitative”, and “quantitative” typologies.

The list of typologies and methodological categories by group – categories, decades, typologies, and groups (from one to six) – shows that in the 1970s, within the “analysis” category, there was an initial emergence of “conceptual” and “quantitative” methodologies (Figure 4). These methodologies were primarily applied to groups 1 (agricultural economics and development) and 2 (technological innovation and performance), indicating a nascent focus on these study areas during that period. In the 1980s, the “analysis” category expanded to include qualitative approaches, particularly in groups 3 (food security and climate change) and 4 (sustainable development and resource management), in addition to the continued use of quantitative approaches.

In the 1990s, there was a balance between qualitative and quantitative approaches in “analysis”, covering groups 1 to 4. In the 2000s, due to the greater number of publications, the “design” and “data collection” categories gained prominence, with an increase in conceptual and qualitative typologies, mainly in groups 5 (“social impacts and institutional transformations in agricultural research”) and 6 (“adoption of sustainable agricultural technologies and practices”). In the 2010s,

		Conceptual						Qualitative						Quantitative					
Category	Decade	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Analysis	1970				2						1			1			2		
	1980							1						3		2	3		2
	1990					1					1		1	2	1		4	1	
	2000	1	1	2		2	1		2		2	1	5	7	3	5	4	5	
	2010	2	1	1		3			2	7		6	4	18	29	7	6	6	8
	2020		1		2	3	2		1	1	1	5	4	9	9	1	4	7	12
Analysis/Design	2010											1							
	2020											1							
Data Collection	1970							1				1							
	1980												1						
	1990							2	1		1								
	2000							2	1	1	1		1						
	2010							5	2	5	2	16	5						
	2020							2		5	1	5	7						
Design	1960				1												1		
	1970										1						1		
	1980	1																	
	1990				1							1	1	1					1
	2000			1	6	2		2	1	2	2	4		1	1	1	1	1	
	2010			2		2		2	2	2	1	8	1	3	3	1		4	
	2020		1	2	1			3	1	2	1	5	7						

Figure 4. List of typologies and methodological categories by group (1 to 6).

Groups/topics: 1. agricultural economics and development; 2. technological innovation and performance; 3. food security and climate change; 4. sustainable development and resource management; 5. social impacts and institutional transformations in agricultural research; and 6. adoption of sustainable agricultural technologies and practices.

the "analysis" category reached maximum diversity, with strong use of qualitative and quantitative approaches across all six groups. The "data collection" category also saw an increase in qualitative approaches, indicating an appreciation for contextual data.

Up to 2020, the trend toward methodological diversification persists in "analysis", showing balanced use across all typologies. "Design" also incorporates conceptual and qualitative approaches. The methodologies identified in the studies are organized into three main categories – "analysis", "data collection", and "design" – and indicated with their typologies according to Weisshuhn et al. (2018), their classification as an approach, method, or technique, and their frequency of use over the decades (Table 7).

Thematic groups versus methodologies

Complementary to Table 7, Figure 5 highlights the frequently used methodologies within the six thematic groups. Group 5 – "social impacts and institutional transformations in agricultural research" has the largest number of distinct methodologies, totaling 35 ones. Among the most prominent methodologies are "qualitative analyses," "case studies," "environmental impact assessment (EIA)," "literature reviews," and "surveys." It is noted that the number of methodologies applied in this group increased significantly from the 2000s onward, reflecting a growing interest in social and institutional impacts.

Table 7. Methodologies identified in agricultural research impact studies.

Category	Typology (Weisshuhn et al., 2018)	Method/technique/approach	Type	Decade						
				1960	1970	1980	1990	2000	2010	2020
Analysis	Conceptual	Analytic hierarchy process (AHP)	Method	0	0	0	0	1	1	0
		Collaborative approach	Approach	0	0	0	0	3	1	2
		Fuzzy logic	Method	0	0	0	0	0	2	0
		Input output model	Method	0	0	1	0	1	0	0
		Integrated assessment models (IAMs)	Method	0	0	0	0	1	0	0
		Mixed methods	Approach	0	1	0	1	4	5	6
		Operations research (OR)	Approach	0	0	0	1	0	2	1
		Research excellence framework (REF)	Method	0	0	0	0	0	1	0
		Scenario	Approach	0	0	0	0	3	2	3
	Qualitative	Adoption analysis	Method	0	0	0	3	8	9	4
		AMBITEC-AGRO	Method	0	0	0	0	0	1	0
		ASIRPA	Method	0	0	0	0	0	2	0
		Content analysis	Technique	0	0	0	0	0	0	1
		Expert opinion	Technique	0	0	0	0	1	1	0
		Literature review	Technique	0	2	1	0	3	10	6
		Qualitative analysis	Method	0	0	0	3	12	13	9
		SIAMPI	Method	0	0	0	0	0	1	0
	Quantitative	Altmetrics	Method	0	0	0	0	0	1	0
		Bayesian analysis	Technique	0	0	0	0	2	0	0
		Bibliometric analysis	Method	0	0	0	0	0	2	5
		Comprehensive level index	Method	0	0	0	0	0	1	0
		Computable general equilibrium	Method	0	0	0	0	0	1	0

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Cadernos de Ciência & Tecnologia, Brasília, v. 42, e27611, 2025
DOI: 10.35977/0104-1096.cct2025.v42.27611

Table 7. Continuation.

Category	Typology (Weisshuhn et al., 2018)	Method/technique/approach	Type	Decade						
				1960	1970	1980	1990	2000	2010	2020
Analysis	Quantitative	Cost effectiveness analysis	Method	0	0	1	1	3	2	0
		Costs benefits / benefit cost ratio	Technique	0	1	2	0	3	1	3
		Data science and analytics	Method	0	0	0	0	0	1	1
		Data envelopment analysis (DEA)	Method	0	0	0	0	0	1	0
		Descriptive statistics	Technique	0	0	1	0	0	9	3
		Dynamic programming	Method	0	1	0	1	0	2	0
		Ecological footprint analysis	Method	0	0	0	0	2	1	1
		Econometric analysis	Method	0	0	1	3	7	7	3
		Effective response	Method	0	0	0	0	0	1	2
		Environmental impact assessment (EIA)	Method	0	0	1	1	5	4	1
		Environmental valuation	Method	0	0	0	0	0	0	1
		Factor analysis	Technique	0	0	0	0	0	2	0
		General equilibrium model	Technique	0	0	0	0	0	1	1
		Index system	Technique	0	0	0	0	0	11	1
		Internal rate of return	Technique	0	0	1	1	0	4	0
		Kernel extraction	Technique	0	0	0	0	0	1	0
		Life cycle analysis (LCA)	Method	0	0	0	0	0	0	1
		Monte Carlo analysis	Technique	0	0	0	0	0	3	0
		Nonlinear programming	Technique	0	1	0	1	0	1	0
		Output analysis	Technique	0	0	0	0	2	0	1
		Panel data	Technique	0	0	0	0	1	3	2
		Patent analysis	Technique	0	0	0	0	1	2	1
		Pathway analysis	Technique	0	0	0	0	3	1	2
		Payback periods	Technique	0	0	0	0	0	1	0
		Performance measurement / contribution analysis	Technique	0	0	1	1	0	6	4
		Principal component analysis (PCA)	Technique	0	0	0	0	0	3	3
		Propensity score matching	Technique	0	0	0	0	0	1	0
		Quantitative analysis	Method	1	4	1	7	8	30	15
		Regression analysis	Technique	0	0	1	0	1	12	8
		Risk analysis	Technique	0	0	0	0	1	1	3
		Scientometric analysis	Method	0	0	1	0	0	3	1
		Sensitivity analysis	Technique	0	0	0	0	0	2	0
		Social network analysis (SNA)	Technique	0	0	0	0	1	0	3
		Spatial distribution	Technique	0	0	0	0	0	0	1
		Statistical models	Technique	0	0	0	2	2	0	3
		Time series analysis	Technique	0	0	0	0	1	3	2
		Votecount method	Technique	0	0	0	0	0	1	1
Analysis/ data collection	Conceptual	Grey system theory	Technique	0	0	0	0	0	2	0
	Qualitative	Case studies	Technique	0	2	0	4	7	25	7
		Interviews	Technique	0	0	0	0	0	6	3

Continued...

Table 7. Continuation.

Category	Typology (Weisshuhn et al., 2018)	Method/technique/approach	Type	Decade						
				1960	1970	1980	1990	2000	2010	2020
Analysis/ design	Qualitative	Impress	Method	0	0	0	0	0	1	1
Data collection	Qualitative	Delphi survey	Technique	0	0	0	0	0	1	1
		Focus groups	Technique	0	0	0	0	0	1	1
		Surveys / questionnaires	Technique	0	0	0	0	3	15	15
Design	Conceptual	Design methodology approach	Approach	0	0	0	1	0	0	0
		Design thinking	Approach	0	0	0	0	0	0	1
		Framework proposed	Approach	0	0	0	1	3	2	5
		Theoretical model	Approach	0	0	0	0	2	0	1
		Theory of change	Approach	0	0	0	0	0	1	1
	Qualitative	Participatory approach	Approach	0	0	0	0	5	5	6
	Quantitative	Experimental designs	Approach	0	0	0	0	0	1	0

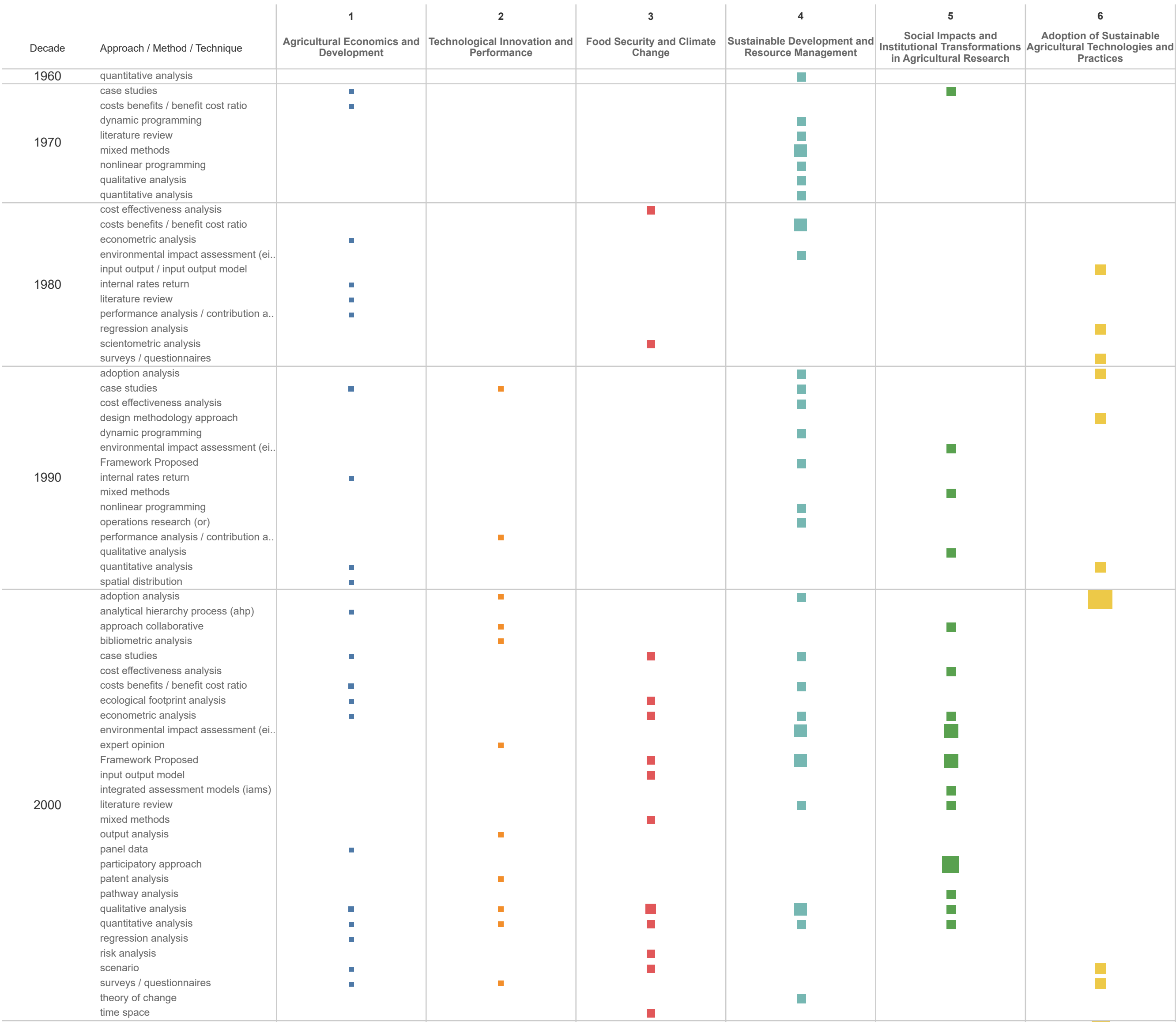

Figure 5. Most frequently used methodologies across thematic classes over time.

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Cadernos de Ciência & Tecnologia, Brasília, v. 42, e27611, 2025
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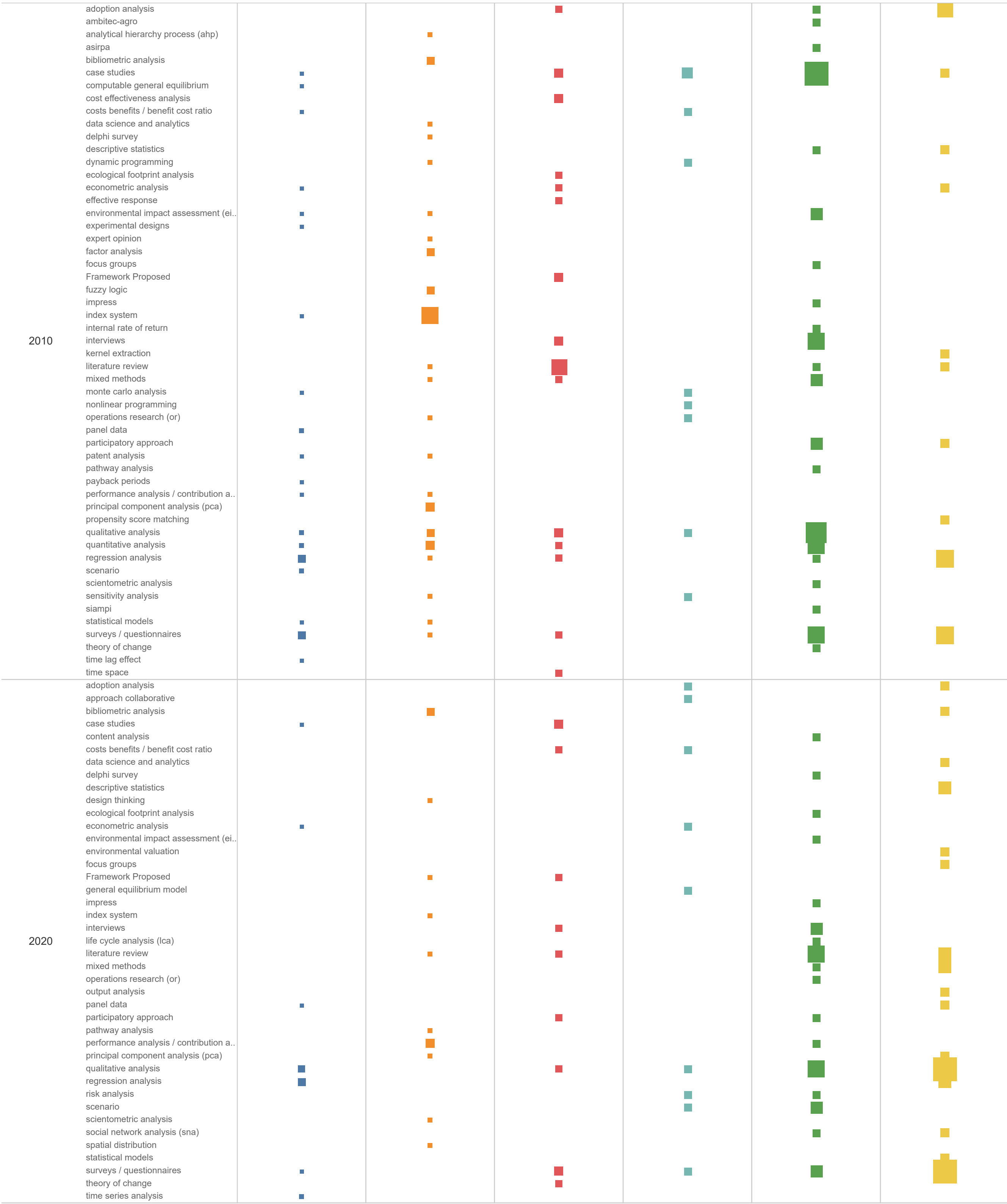

Figure 5. (Continued) Most frequently used methodologies across thematic classes over time.

In second place, with 31 distinct methodologies, is "group 2 – technological innovation and performance," in which "index system" stands out, followed by "performance analysis / contribution analysis" and "bibliometric analysis." The number of methodologies in this group has grown significantly since the 2010s.

In third place, with 25 distinct methodologies each, are "group 1 - agricultural economics and development", and group "6 - adoption of sustainable agricultural technologies and practices." In group 1, the most prominent methodologies include "regression analyses," "qualitative analyses," "case studies," and "scenarios," which became more prevalent from the 2000s onward. Nevertheless, group 6 shows a significant increase in methodological diversity from the 2010s, with "surveys" being the most prominent one, followed by "adoption analyses" and "regression analyses."

In fourth place, also tied, are group "3 - food security and climate change" and group "4 - sustainable development and resource management", both with 22 distinct methodologies. Group 3's primary technique is "literature review," followed by "case studies" and "framework proposed," with a significant increase in methodological diversity starting in the 1990s. Meanwhile, group 4 also shows growth in methodological diversity from the 1990s onward, with "costs benefits / benefit cost ratio," "qualitative analyses," "cost effectiveness analysis," and "case studies" standing out, reflecting the importance of sustainability in agricultural resource management.

DISCUSSION

The present analysis shows that the methodological complexity varies according to the thematic focus, highlighting the need for a greater methodological diversification in certain research areas. This dynamics is shows (Figure 2) that although group "1 - "agricultural economics and development" – stands out as the segment with the highest volume of publications, it ranks only third for the number of methodologies employed. In contrast, group "5 - social impacts and institutional transformations in agricultural research" –, which focuses on themes related to social impacts and institutional transformations, has the widest methodological breadth, reflecting a significant effort to integrate diverse approaches. These findings suggest that researches addressing more complex social challenges inherently require a broader and more interdisciplinary methodological spectrum, capable of capturing the multiple dimensions of the transformations under analysis.

Overall, sustainability-related themes were found as prominent in the evaluation of agricultural research, as noted in the literature (FAO, 2000, 2011, 2022; Rodrigues & Rodrigues, 2007; Pingali, 2012; Claudino & Talamini, 2013). These themes of sustainable development are closely linked to other challenges faced by developing countries, such as food security and the need to mitigate the effects of climate change. The broad scope of these issues emphasizes the critical importance of sustainability in agriculture. In examining their connection to methodologies, a wide range of approaches, methods, and techniques are evident in the evaluation of agricultural research impacts, as reported by studies Pretty et al. (2000) and Pretty & Bharucha (2014).

The SDGs and their interconnection with agriculture emerged in relation to impact studies, particularly from the 2020s onward (FAO, 2022). The crops identified in the analysis – rice, wheat, potato, and yam – exemplify the intersection between public agricultural research policy agendas and the SDGs. These crops address critical global challenges, such as food security and climate change, particularly in developing countries. They are also vulnerable to climate change, with implications for natural resource use, agricultural productivity, and food security (FAO, 2022). This context directly

Cadernos de Ciência & Tecnologia, Brasília, v. 42, e27611, 2025
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connects these crops to SDG 2, which addresses food security, and SDG 13, focused on climate action, as reflected in the results. Potatoes and yams hold similar relevance, especially in regions such as Africa and China. These findings stress the practical value of aligning research impact evaluations with regional and crop-specific strategies, addressing vulnerability and sustainability in diverse contexts.

The analysis of methodologies adopted over time shows a decline in the use of qualitative techniques, which were prominent in the 1990s and 2000s, and contrasts with the findings by Weisshuhn et al. (2018). Quantitative techniques, such as regression analysis and bibliometric analysis, now predominate over qualitative ones. However, this does not imply the exclusion of qualitative approaches. Instead, it may indicate a methodological evolution in response to the increasing complexity of the problems being investigated. In this context, the use of mixed methods – combining aspects of qualitative and quantitative methodologies – has become increasingly prevalent and necessary since the 2000s, as displayed in the analysis. It reflects a theoretical shift toward recognizing impact evaluation as a multidimensional process and suggests practical pathways for fostering interdisciplinary collaborations and method diversification. This shift also presents challenges, such as the need for researchers to develop interdisciplinary skills and the difficulty of ensuring methodological rigor when combining different approaches. Moreover, the adoption of advanced data science and analysis techniques highlights the growing need for sophisticated tools, to handle data complexity and interpret their meanings in the context of the problems under study. Nevertheless, not only the growing use of mixed methods and advanced data techniques meet the demands of complex research questions, but they also pave the way for future interdisciplinary collaboration.

While the predominance of ex post studies and nonexperimental approaches identified in the research aligns with the observations of Weisshuhn et al. (2018), the findings diverge from those of the World Bank team, which reported a predominance of *quasi* experimental studies in their research. However, a common observation is the limited number of experimental studies, particularly RCTs, which underscores the challenges associated with the use of these trials, as noted by Norton & Alwang (2016).

As to gaps, no studies were identified that evaluate the impact of agricultural research on specific crops across different socioeconomic and geographic contexts. For instance, although crops such as rice, wheat, potato, and yam were identified, they were not necessarily the subject of evaluation. According to Ray et al. (2022), ten crops are most relevant in the context of global food security, out of which eight were identified in the sample. Despite this fact, the volume of studies on these crops is small, representing approximately 10% of the total analyzed. This gap presents an opportunity for future research to explore how impact evaluations, with their diverse methodologies, could feedback into agricultural R&D organizations, shaping their internal organization, research priorities, and enhancing the social relevance and impact of their activities.

CONCLUSIONS

Natural language processing (NLP) techniques like tokenization and topic modeling offer an innovative approach to extract insights from publication datasets. This framework integrates multidimensional approaches for impact evaluation, addressing the complexity of contemporary challenges in the agricultural sector. By combining bigram analysis with topic modeling, the study offers a comprehensive view of emerging themes, while constructing a dictionary of methodologies, providing a tool for policymakers and strategists to prioritize investments in sustainability, food security, and climate change.

A key theoretical contribution lies in positioning impact evaluations as strategic tools within the frameworks of RRI and RRA. Evaluations are not shown as merely measurement tools, but as mechanisms of institutional responsibility addressing global challenges such as environmental sustainability and social equity. The methodological innovation showed through NLP and bigram analysis also establishes a benchmark for using computational approaches to identify patterns and gaps in large textual datasets, setting a precedent for their broader application across various research domains.

From a practical standpoint, the study offers insights related to the SDGs, enabling institutions to justify and enhance investments in globally critical areas. The findings emphasize the potential of diverse and mixed methodologies, which combine qualitative and quantitative approaches as key tools for more robust evaluations and strategic decision-making. This recommendation is further supported by the development of a dictionary of methods, which serves as a practical guide for researchers and evaluators.

However, some limitations should be acknowledged. The reliance on Scopus and Web of Science databases may introduce selection bias, excluding studies outside these databases. The results of the unsupervised data analysis are also constrained by the limitations inherent to the NLP techniques employed. The themes identified through bigram analysis and topic modeling serve as a proxy, providing an overview of common patterns and concerns observed in the literature. As such, the insights should be interpreted as indicative of broader trends, rather than definitive conclusions. The identification of thematic trends based on the cumulative frequency of bigram occurrences provides valuable insights, but it may not fully capture the complexity and nuances of emerging topics. Despite these limitations, the study emphasizes the need for methodological evolution, where new approaches expand the evaluators' toolbox, without displacing traditional ones, enabling more precise and responsible analyses of agricultural research impacts.

By organizing agricultural research impact studies, not only this work identifies key themes and emerging trends, but it also shows the strategic value of impact evaluations in guiding institutional policies. These evaluations foster ethical and socially aligned innovations and contribute to global agricultural resilience. Ultimately, this study advances both the theoretical understanding and the practical application of impact evaluations in an ever-evolving research landscape.

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