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Cultivating equality in next-gen agriculture through gender-inclusive extension: A bibliometric analysis

SWEETY MUKHERJEE[1], RABINDRA NATH PADARIA[1]*, RAJARSHI ROY BURMAN[2], KOTHA SHRAVANI[1], SUSHMITA SAINI[1], BHASKAR GHOSH[1] and SIMRAN PUNDIR[1]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

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ABSTRACT

The advancement of next-gen agriculture hinges on integrating cutting-edge technologies and innovative approaches to improve productivity, efficiency, and sustainability. However, achieving true progress requires dismantling traditional gender barriers and ensuring women's active participation in agricultural decision-making, training, and resource access. The present study was carried out for a period of 1988–2023 to provide a bibliometric analysis of research on gender-inclusive extension in next-gen agriculture. The study highlighted the significant contributions of women in farming and the persistent gender disparities that impede agricultural productivity and sustainability. The findings indicated a significant emphasis on Zero Hunger (SDG 2) and Gender Equality (SDG 5), underscoring the global priority to tackle food security and gender inequality. The quantum of publications on gender-inclusive development has increased notably since 2009, peaking in 2023. Co-word analysis uncovered interconnected themes like climate change adaptation, extension services, and the integration of smallholder farmers, highlighting the multifaceted nature of gender dynamics in agriculture. Co-authorship analysis revealed substantial international collaboration, with the USA being the primary contributor. The study also provided a framework for gender-inclusive extension in next-gen agriculture based on CIPP model. By promoting gender-responsive policies, capacity building, inclusive programme design, and financial inclusion, the study advocated for a holistic approach to cultivating equality in agriculture. The findings emphasised the critical role of gender dynamics in shaping agricultural advancements and the necessity of fostering an inclusive agricultural ecosystem to address global challenges such as food security and environmental sustainability.

Keywords: Gender disparities, Gender dynamics, Next-gen agriculture, Sustainable development goals

In the contemporary agricultural context, the use of cutting-edge technologies, data-driven methods, and innovative approaches to improve the efficiency, productivity, and sustainability of farming is termed as 'next-gen agriculture'. With the introduction of innovative practices like precision agriculture (PA), biotechnology, automation, artificial intelligence (AI), and the Internet of Things (IoT) into the agricultural landscape, it marks a break from conventional farming practices (Saiz-Rubio and Rovira-Mas 2020). Next-gen agricultural practices (NGAP) strive to optimise resource utilisation, reduce environmental impact, and increase overall crop yields in order to address issues like food security, climate change, and resource constraints (Fuentes-Penailillo *et al.* 2024, Mukherjee *et al.* 2026). In addition, this modernisation of agriculture also encompasses a broader perspective that takes into account social, economic, and environmental sustainability of farmers as well as of farm women. The purpose of NGAPs is to develop a more resilient and productive agricultural sector that can satisfy the gender-inclusive needs of an expanding world population in an ever-changing environment (Saiz-Rubio and Rovira-Mas 2020).

The current landscape of gender in agriculture indicates the existence of large gender disparities in access and control regarding the six essential resources for agriculture—land, labour, credit, information, extension, and technology (World Bank and IFPRI 2010, Sheahan and Barrett 2014, Huyer 2016). Starting from 1995–96, the Agriculture Census has included the collection of gender-disaggregated data. The percentage share of female operational holders has gone up from 12.78% in 2010–11 to 13.96% in 2015–16 (Anonymous 2020), showing a growing participation of females in the management and/or operation of agricultural holdings in the nation. The average size of operational holding of female has decreased from 0.93 ha in 2010–11 to 0.90 ha in 2015–16 (Anonymous 2020).

Global gender gaps in vulnerabilities, resource availability, and productivity are characteristics of women's

[1]ICAR-Indian Agricultural Research Institute, New Delhi; [2]Krishi Anusandhan Bhawan-I, New Delhi. *Corresponding author email: rabindrapadaria@rediffmail.com

agricultural activities (Quisumbing and Pandolfelli 2010, FAO 2011, Perez *et al.* 2015, Huyer 2016). The gender gap in agricultural productivity in terms of the value of agricultural produce per unit of cultivated land varies from 4–25%, depending on the country and crop, according to a study led by the World Bank. Also, the cost of the gender gap in agriculture is estimated to be $100 million in Malawi, $105 million in Tanzania, and $67 million in Uganda (Buehren *et al.* 2015, Huyer 2016). Despite the important role that women perform on farms, men are frequently the ones who are labelled as 'farmers' (Peter *et al.* 2000). Additionally, research indicates a strong correlation between conventional farming and rural masculinities (Farnworth and Hutchings 2009). This perception has increased rather than decreased since the beginning of mechanisation (Peter *et al.* 2000). Although mechanisation per se does not keep women out of farming, data indicated that it has driven some of them out of the fields (Farnworth and Hutchings 2009). It's challenging to dispel the societal belief that agriculture is a field best left to men (Bock and Shortall 2017). This view has the effect of making women on farms more likely to defer to men when making decisions (Carter 2017). These cultural conceptions further solidify agriculture as a masculine environment by establishing strongly male-gendered spaces (Farnworth and Hutchings 2009).

Irrespective of the developmental status of their economies, women play a crucial role in agriculture and rural development across many countries in the Asia-Pacific Region (Prakash 2003). However, understanding the role of women in agriculture requires considering their positions within households, communities, and nations, challenging the notion of treating women as a homogeneous group, given differences in land ownership and tenancy (Chinyemba *et al.* 2006). The significant knowledge of women in food production, processing, storing, and marketing, child nurturing, breeding of food crops, seed preservation, and the use of wild edible plants have been acknowledged (Okwu and Umoru 2009, Raidimi 2014, Ugboma 2014). Therefore, a study was carried out with the objective to comprehend the significance of gender in agricultural extension through a framework of bibliometric analysis to achieve Sustainable Development Goals (SDGs) in the 'next-gen agriculture'. The present study used CIPP (Context-Input-Process-Product) framework to address three major research questions namely 1) What is the total number of NGAP's publications on SDGs themes?, 2) What is the timeline of growth of publications over the years in the NGAPs for gender inclusive development?, and 3) What are the main thematic areas with their countries that are publishing on modern technologies in agriculture with respect to gender inclusive development?

MATERIALS AND METHODS

Conceptual framework: To strengthen the interpretative depth of the bibliometric analysis, the findings were analytically integrated with the CIPP evaluation framework (Table 1). This framework enables systematic linkage between mapped research trends and their implications for gender-inclusive extension systems. The bibliometric outputs such as Sustainable Developmental Goal (SDG) mapping, thematic clustering, and co-word analysis were aligned with the four evaluative dimensions of the CIPP model to provide a structured policy-relevant interpretation.

Data source and database selection: The bibliometric data were retrieved exclusively from the Dimensions.ai database due to its extensive coverage of peer-reviewed articles, conference proceedings, books, and policy-oriented publications, along with its inclusion of Global South research outputs and open-access metadata (Saini *et al.* 2023, Padhan *et al.* 2024). However, this database was deemed appropriate for trend-mapping due to its integrated citation, funding, and policy linkages, which are not simultaneously available in Scopus or Web of Science.

Search strategy: Only peer-reviewed scholarly documents (journal articles, conference papers, book chapters) were included. Editorials, news items, project reports, theses, and unpublished grey literature were excluded. English-language publications were considered to ensure consistency in keyword extraction and co-word analysis. The search query ('Gender' and 'Agriculture' and 'Extension') was applied to titles and abstracts to ensure thematic relevance and to minimise retrieval of peripheral and non-substantive records. Documents that explicitly addressed gender dimensions in agriculture and extension, as reflected

Table 1 Analytical integration of the bibliometric study with CIPP framework

CIPP criteria	Analytical objective	Bibliometric basis for methods
Context	Examine alignment of research with SDGs, identify gender gaps, and map dominant policy discourse in next-gen agriculture	Derived from SDG classification, publication trends, and high-frequency keyword analysis
Input	Identify institutional capacities, governance mechanisms, and gender-responsive resource structures influencing extension systems	Inferred from thematic clusters and co-authorship network analysis
Process	Analyse extension approaches, ICT integration, participation patterns, and implementation modalities	Derived from co-word network analysis and thematic evolution mapping
Product	Assess research emphasis on outcomes such as women's empowerment, technology adoption, inclusion, and sustainability	Interpreted from dominant research themes and keyword density visualisation

in titles or abstracts were included. While alternative terminologies were avoided to ensured conceptual precision and reduced semantic dilution during co-word analysis. The period 1988–2023 was selected as 1988 marks the emergence of gender-focused agricultural development discourse following global policy milestones emphasising women in development. The selected timeframe captures the evolution of gender discourse from early development paradigms to contemporary next-gen agriculture, enabling longitudinal analysis of thematic shifts. This search strategy gave an extensive dataset of 441 publications including scholarly articles, proceedings, monographs, and other publications.

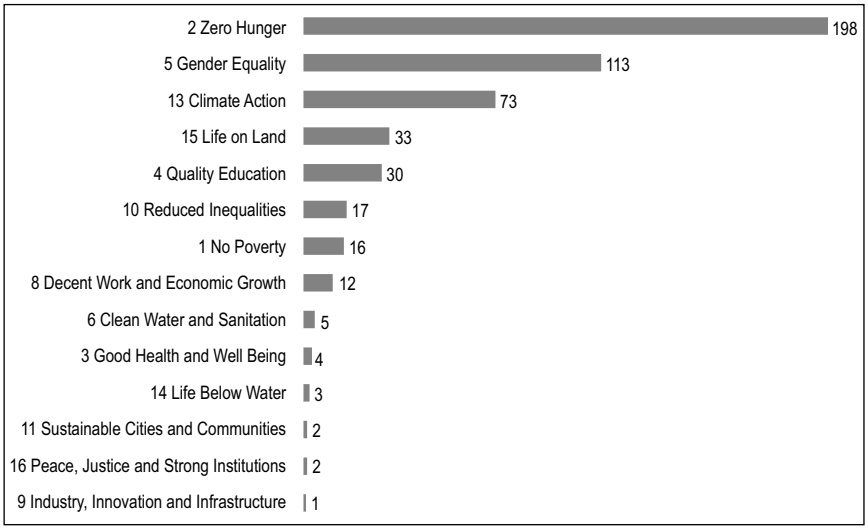

Fig. 1 Number of publications in each research category of SDGs.

Retrieval protocol: As part of the analysis, number of publications in different research category of SDGs, publication trends over time, different nations contributing to the field, and co-occurrence of words were visualised (Mukherjee *et al.* 2025b). The publications were assigned to SDGs based on dominant thematic alignment inferred from abstracts and keywords, following UN SDG metadata guidance. Overlapping SDG relevance was resolved by prioritising primary research objectives. This approach allowed for a systematic and quantitative exploration of the research landscape, offering insights into the evolution, impact, and key players at the nexus of gender, agriculture, and extension studies.

Data analysis: After conducting the search, the retrieved dataset was exported as a CSV file for further analysis. The softwares such as Microsoft Excel was used for preliminary data cleaning and frequency analysis, while VOSviewer (v1.6.18) facilitated network visualisations based on association strength normalisation. R software (v4.2.2) supported descriptive statistical validation. Network visualisations provide heuristic representations of research linkages; however, node proximity and density should be interpreted as relational tendencies rather than hierarchical relationships (Mukherjee *et al.* 2025b).

RESULTS AND DISCUSSION

The distribution of total number of NGAP's publications in SDGs themes indicated that out of the 17 SDGs, a notable emphasis was given on Zero Hunger (SDG 2) and Gender Equality (SDG 5) (Fig. 1). This focus aligns with the global imperative to address food security and gender disparities in agriculture. Currently, around 815 million people suffer from hunger worldwide, a crisis exacerbated by factors such as food waste, biofuel production, and rapid population growth (FAO 2017). By 2050, the agricultural sector needs to produce approximately 50% more food to feed an estimated nine billion people. Women, despite contributing significantly to agricultural labour, face substantial productivity gaps, yielding 20–30% less than their male counterparts in developing nations (FAO 2011). This gender disparity extends to developed economies, where only about 25% of agricultural scientists are women (Huyer 2016). Addressing these imbalances is critical for enhancing food security and achieving SDG targets. Publications focusing on gender equality in agriculture also highlight the need for equitable access to resources and opportunities, which is essential for sustainable development (World Bank and IFPRI 2010, Sheahan and Barrett 2014). The research contributions in these categories underscore the importance of integrated approaches that consider social, economic, and environmental dimensions to achieve holistic sustainable development.

The timeline of growth of publications over the years in the NGAPs for gender inclusive development (Fig. 2) depicted a steady increase in the number of publications since 2009, with the highest number of publications recorded in the year 2023 with 67 articles. Following this, 65 articles were published in 2022, and 59 articles in 2021, demonstrating an ongoing interest and involvement of scholars with the subject of gender in agriculture.

The overlay visualisation of co-word analysis (Fig. 3) revealed prominent themes and clusters related to NGAPs, gender dynamics, and climate change adaptation. This visualisation underscored the interconnected nature of these themes and highlighted the significant research focus on addressing hunger and gender disparities in agriculture. Central themes, such as the roles of women and smallholder farmers, were prominently featured, indicating their importance in the field. Key terms like 'extension service', 'climate change', 'adoption', and 'development' were highly interconnected, underscoring the multifaceted nature of gender dynamics in agricultural practices (Mukherjee *et al.* 2026). The colour gradient, ranging from blue to yellow, highlighted a temporal shift towards recent studies focusing on climate adaptation and the integration of smallholder farmers into cooperative frameworks. The visualisation

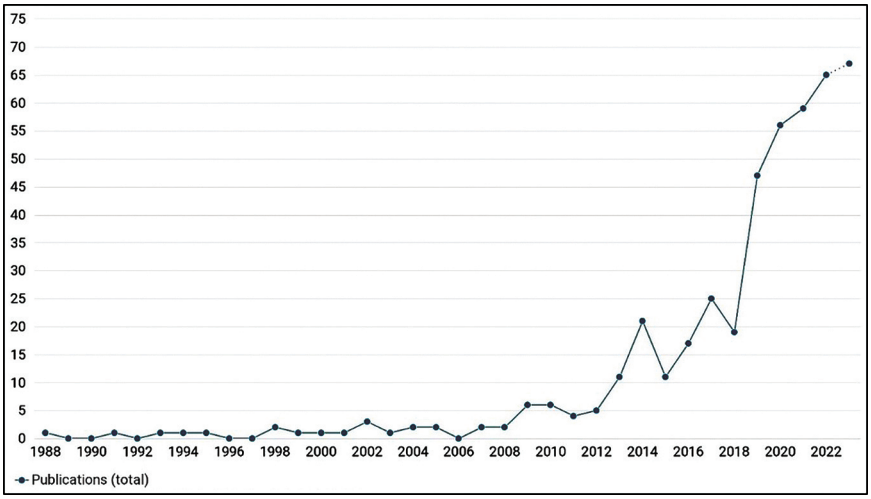

Fig. 2 Number of publications published in each year..

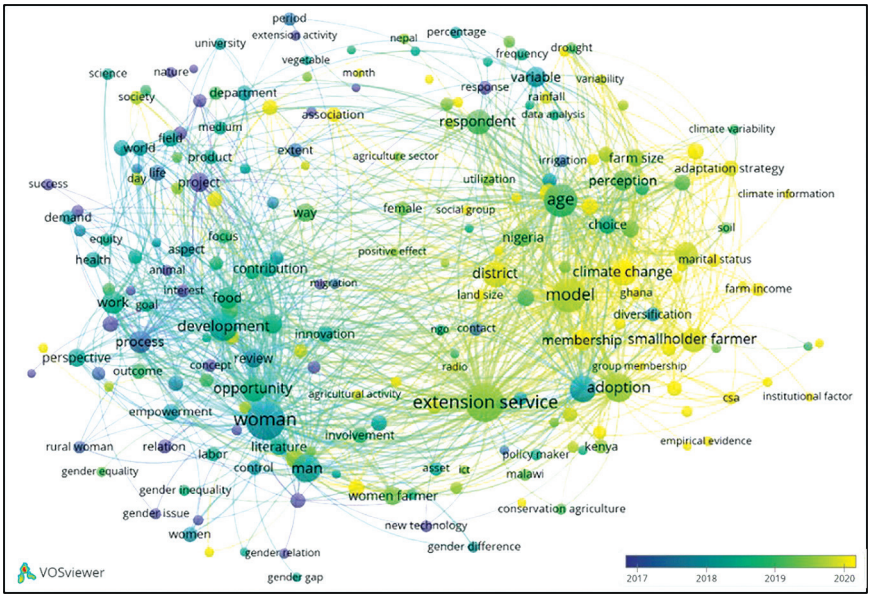

Fig. 3 Overlay visualisation of co-word analysis of titles and abstracts. Each node indicates a word, each line indicates link between words, thickness indicates their co-occurrence, and colour of the cluster reflects duration of publication of articles.

also highlighted the importance of gender-disaggregated data, as seen in the cluster around 'female' and 'farm size'. The Agriculture Census, which has included gender-disaggregated data since 1995–96, showed a growing participation of females in managing agricultural holdings, though the average size of female operational holdings remains smaller (Anonymous 2020). Women's crucial roles extend beyond labour to include post-harvest processing, storage, and marketing, contributing significantly to the agricultural value chain (Karl 2009). This multifaceted involvement is reflected in the diverse terms associated with women's agricultural activities, emphasising the need for policies and interventions that address gender disparities and promote equality in agriculture. This analysis not only mapped the intellectual structure of the research field but also identified emerging trends and potential research gaps, particularly at the intersection of gender issues and climate adaptation strategies, offering valuable insights for future studies.

The density visualisation of co-authorship analysis using VOSviewer software, weighted by the number of documents revealed significant collaboration among 23 countries in the research field (Fig. 4). The USA led with the highest number of documents (55), while India with 16 documents, highlighting their prominent roles in international research partnerships. The density visualisation showed the USA as the central hub of co-authorship (yellow areas), indicating extensive collaborative activity. Other notable contributors included Nigeria, Kenya, and the United Kingdom, with varying levels of activity. This visualisation underscored the global nature of research on gender-inclusive agricultural extension, with notable contributions from both developed and developing countries.

Policy recommendations and strategies: The policy recommendations presented below are directly derived from the bibliometric patterns identified in the analysis, including dominant SDG focus areas, emerging thematic clusters, and geographical collaboration trends:

Gender-responsive policy framework for advancing SDG 5 (Gender Equality): Promote and carry out policies that take gender into account, making sure that agricultural extension programmes cater to the distinct needs and difficulties encountered by both male and female farmers.

Capacity building of extension personnel to achieve SDG 2 (Zero Hunger) and SDG 1 (No Poverty): Offer comprehensive training programmes that emphasise gender sensitivity, effective communication, and the ability to adapt agricultural advice to the various needs of both male and female farmers. For instance, sensitisation and scaling up of extension professionals' research competencies were greatly impacted by Division of Agricultural Extension, Indian Council of Agricultural Research (ICAR), via initiatives like extra-mural research projects, Farmer FIRST, Attracting and Retaining Youth in Agriculture (ARYA) and New Extension Methodologies and Approaches (NEMA), as well as capacity-building of extension professionals through international organisations (Ponnusamy and Padaria 2021).

Gender-integrated programme design for SDG 10 (Reduced Inequalities) and SDG 5 (Gender Equality):

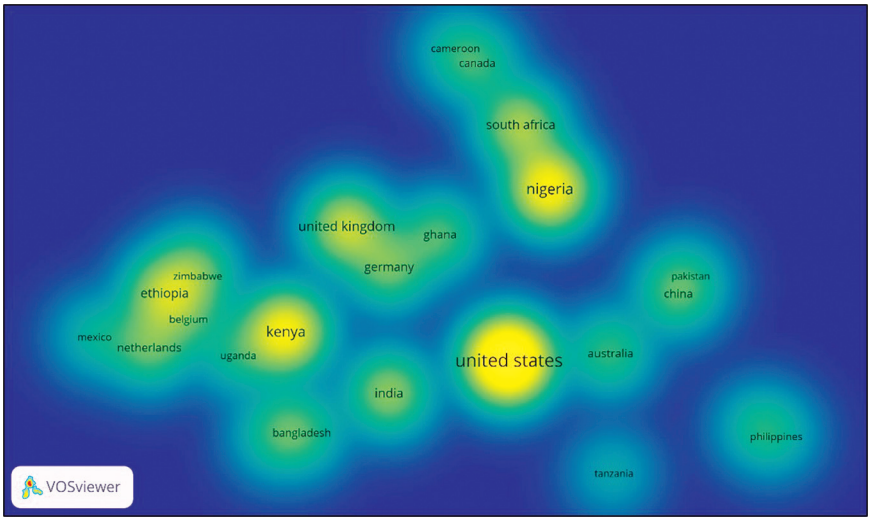

Fig. 4 Density visualisation of co-authorship analysis of countries. Each node represents a country, and the density represents the co-authorship of the countries in research publications.

To ensure inclusivity and efficacy, integrate a gender perspective while designing extension programmes, taking into account the roles, preferences, and limitations of women in agriculture.

Women's leadership development in extension systems supporting SDG 5 (Gender Equality) and SDG 16 (Inclusive Institutions): Develop initiatives that empower women to assume leadership positions in extension services and encourage their active participation in organisational and community decision-making processes. For instance, Gender Advancement for Transforming Institutions (GATI), launched by the WISE-KIRAN, Division of the Department of Science and Technology (DST) on National Science Day 2020, promotes gender equity in Science, Technology, Engineering, Medicine and Mathematics (STEMM) disciplines. This institute represents gender-responsive institutional design as well as cross-sector institutional model. It supports diversity and inclusion in higher education and research, aiming to create an environment that ensures equal participation and professional progression for women beyond just recruitment and retention.

Institutionalisation of gender-disaggregated data systems to support SDG 17 (Partnerships for the Goals) and SDG 5 (Gender Equality): Implementing systems for gathering and evaluating gender-disaggregated data will allow for evidence-based planning and assessment of extension programmes, ensuring that they are tailored to the specific needs of both genders (Farhall and Rickards 2021). For instance, the National Institute of Food and Agriculture (NIFA) in the United States places a strong emphasis on the gathering and analysis of gender-specific data in order to inform agricultural policies. Gender-disaggregated data and information are essential for informing gender analysis and designing programmes that lessen inequalities and barriers for both women and men in the agriculture sector (Harvey 2015).

Community engagement and gender sensitisation to advance SDG 5 (Gender Equality) and SDG 4 (Quality Education): Without realising the physical and cultural barriers preventing women from obtaining the most essential services, many systems have placed a larger focus on promoting various agricultural extension initiatives. In rural areas, this has mostly led to women's uneven access to Extension and Advisory Services (EAS) (Beevi *et al.* 2018). Conducting awareness campaigns in communities to dispel gender stereotypes, highlight the contributions made by women in agriculture, and motivate men and women to actively participate in extension activities.

Financial inclusion mechanisms for women farmers to achieve SDG 8 (Decent Work and Economic Growth) and SDG 1 (No Poverty): Promote and assist women farmers in accessing financial services so they can invest in their farms, follow best practices, and take part completely in agricultural value chains. For instance, under the 'Establishment of Agri-Clinics and Agri-Business Centres (AC&ABC)' central sector initiative introduced in April 2002 by the Extension Division of the Department of Agriculture and Farmers Welfare, women receive higher subsidies (44%) on bank loans for agricultural ventures, thereby promoting self-employment (Saini *et al.* 2025). The initiative seeks to promote women's economic empowerment, strengthen the competitiveness of female entrepreneurs, and create more inclusive business and policy ecosystems.

ICT-enabled extension strategies for women farmers supporting SDG 9 (Industry, Innovation and Infrastructure) and SDG 5 (Gender Equality): Introduce programmes that make use of ICT for women in agriculture. For instance, the 'Digital Green' project in India makes use of technology to provide women farmers with video-based agricultural training, improving their knowledge of next-gen farming practices (Burman *et al.* 2023, Mukherjee *et al.* 2025a).

In the context of India, the recommended strategies may be prioritised based on three key criteria: (i) Institutional feasibility within existing agricultural extension structures, (ii) Alignment with national policy frameworks such as ICAR initiatives, the Department of Agriculture and Farmers Welfare (DA&FW) programmes, and SDG commitments, and (iii) Urgency in addressing persistent gender gaps in access to resources, information, and decision-making. Based on these criteria, the highest priority should be accorded to the institutionalisation of gender-disaggregated data systems, as evidence-based planning forms the foundation of responsive policy design. This should be followed by capacity building of extension personnel to ensure gender-sensitive service delivery across states. ICT-enabled extension models for women

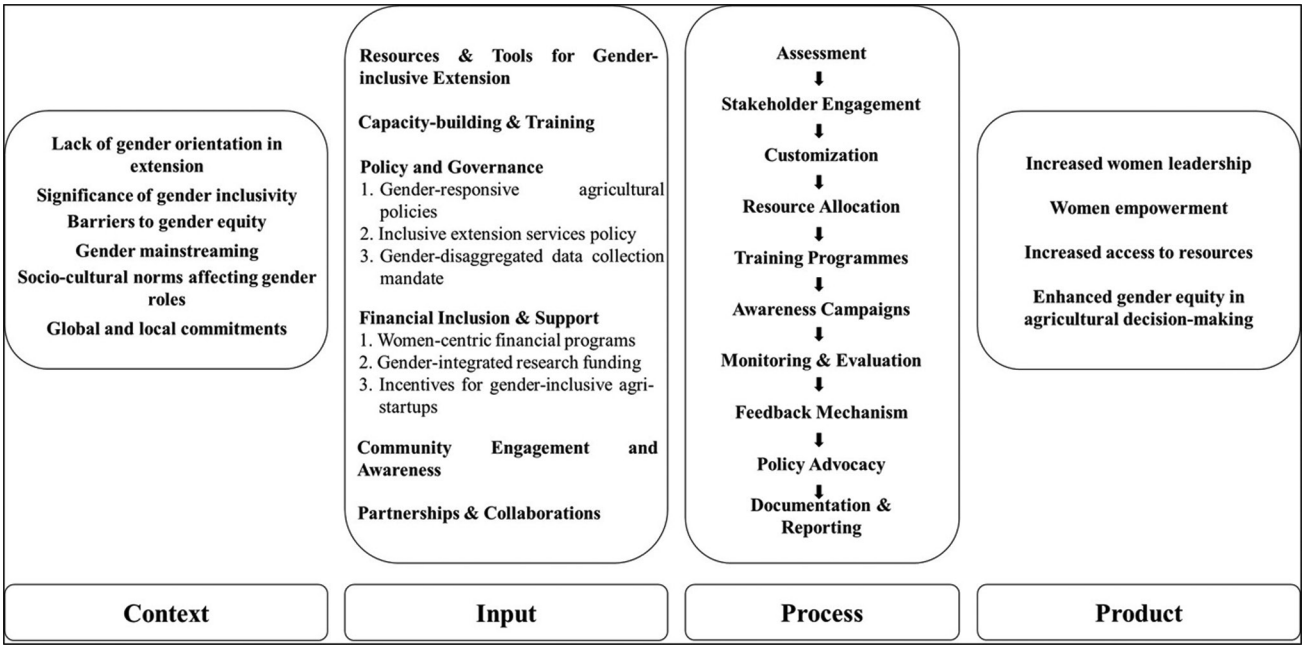

Fig. 5 Suggested framework for gender-inclusive extension in next-gen agriculture based on CIPP model.

farmers represent the next strategic priority due to their scalability and cost-effectiveness in reaching marginalised groups. Finally, financial inclusion mechanisms, while critical, may be phased progressively through convergence with existing credit and entrepreneurship schemes. This sequencing ensures both practical feasibility and maximum developmental impact within India's extension ecosystem (Fig. 5).

In the ever-evolving realm of next-gen agriculture, the lens through which we view progress must focus sharply on the crucial role that gender plays. This study revealed the rise in publications post-2009, dominance of SDG 2 and SDG 5, and gaps in Global South collaboration. The study acknowledged and appreciated the importance of gender dynamics as not just a question of social justice; but also a critical factor in shaping the trajectory of agricultural advancements. Learning how gender affects access, participation, and success in the agricultural sector is crucial as we move towards a future marked by cutting-edge technologies and creative practices. The integration of gender-inclusive practices in next-gen agriculture is imperative for achieving sustainable development. This study underscored the critical role of women in agriculture and highlights the persistent gender disparities that hinder progress. By implementing gender-responsive policies, providing targeted training, and ensuring equitable access to resources, we can foster a more inclusive agricultural ecosystem. Such measures will not only enhance agricultural productivity and sustainability but also contribute to global food security and environmental conservation. Addressing gender dynamics in agriculture is essential for cultivating a more equitable and resilient future in the agricultural sector.

Further, Dimensions.ai provides broad multidisciplinary coverage, it may under-represent niche regional journals, non-English publications, and locally disseminated extension research. Consequently, some context-specific gender-extension studies may not be captured. Future research should integrate qualitative meta-synthesis or case-based reviews for qualitative indicators. Differences in publication output across countries may reflect disparities in research funding, language dominance, database indexing, and institutional capacity rather than actual engagement with gender-inclusive extension.

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