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Participatory agricultural extension: A catalyst for sustainability and farmer empowerment

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Abstract

Participatory methods in agricultural extension have transformed knowledge sharing from top-down models to farmer-initiated, collective approaches. This study discusses some of the main participatory models like Farmer Field Schools (FFS), Participatory Rural Appraisal (PRA), and Participatory Technology Development (PTD), with emphasis on their contribution to promoting sustainable agriculture practices, climate resilience, and participatory agricultural innovation. Based on a secondary research approach, the research examines literature, case studies, and policy structures in order to determine the efficacy of participatory extension in enhancing technology uptake, retention of knowledge, and gender participation. Results indicate that participatory extension increases farmer participation and sustainability but still faces institutional barriers, financial challenges, and socio-cultural obstacles. Policy reforms, digital incorporation, and multi-stakeholder cooperation are policy recommendations made by the study in order to enhance participatory extension. Through enhancing farmers' participation as co-creators of agricultural innovation, participatory methodologies can greatly lead to resilient climate-smart farming and sustainable rural development.

Keywords: Agricultural extension, knowledge-sharing, participatory, sustainability, empowerment, farmer-led, innovation

Introduction

Role of Agricultural Extension in Modern Agriculture

Extension agriculture is highly important in increasing farm productivity, enhancing rural livelihoods, and encouraging sustainable agriculture by disseminating scientific innovations to farmers (Sahu *et al*., 2023) [46]. In the past, it was a top-down, expert-driven model, but gradually, the process has become more participatory in nature, highlighting active involvement of farmers. Against global issues such as climate change, food insecurity, and land degradation (Smith *et al*., 2020) [49], contemporary extension services close the knowledge gap between research and application, empowering farmers with innovations like precision agriculture, climate-resilient crops, and integrated pest management. Yet, conventional extension models tend to experience limitations such as inadequate funding, human resource limitations, and poor communication. The transition towards participatory, inclusive models encourages collaboration between farmers, researchers, policymakers, and private actors, empowering farmers as central actors in agricultural knowledge systems. The change is aligned with sustainable agriculture objectives, supporting the development of robust farming communities with the ability to respond to changing challenges (Chowdhury *et al*., 2014) [7]. In recent years, organizations have increasingly operated in multicultural environments, highlighting the relevance of cross-cultural HRM practices (Vidyawati & Jadoun, 2024) [54].

Importance of Participatory Approaches in Agricultural Extension

The one-way knowledge transfer-based traditional models of agricultural extension have been accused of ignoring the varied agro-ecological settings, knowledge, and socio-economic issues of the smallholder farmers (Lacombe *et al*., 2018) [23]. However, participatory methods acknowledge the farmers as co-producers and not mere passive recipients of knowledge. These approaches focus on social learning, reciprocal knowledge sharing, and empowerment, building collaboration among farmers, extension officers, and scientists to understand problems and create locally appropriate solutions. These participatory extension approaches like Farmer Field Schools (FFS), Participatory Rural Appraisal (PRA), and Participatory Technology Development (PTD) have been found successful in enhancing sustainable farming (Stringer *et al*., 2006) [50]. For example, FFS has helped accelerate integrated pest management, organic farming, and agro-ecology through stimulating experiment-based learning and peer-to-peer learning. Besides, participatory methods ensure that gender and social equity are attended to through extension programs ensuring that women take active participation in programs, taking notice of their expertise in seed quality selection, post-harvest handling, and nutrition-responsive farming (Fadda *et al*., 2020) [11]. Again, participatory extension raises adoption and durability levels of farm innovations. As opposed to technologies that are imposed by others, farmer-initiated solutions are more extensive and practiced. This inclusion of digital tools, such as mobile advisory platforms and social

media, further enhances participatory extension in that it facilitates real-time information sharing and collaborative decision-making, ultimately enhancing agricultural outcomes (Mapiye *et al*., 2023) [31].

Objectives

1. To analyze the role, effectiveness, and impact of participatory approaches in agricultural extension.
2. To assess participatory methods like FFS, PRA, and PTD in promoting sustainable farming practices.
3. To identify institutional, socio-economic, and technological challenges in participatory agricultural extension.
4. To explore future trends and propose a roadmap for digital integration and multi-stakeholder collaboration.

Methodology

This study employs secondary research methodology, reviewing academic literature, case studies, and policy reports on participatory agricultural extension. It explores theoretical frameworks such as Participatory Action Research and Agricultural Knowledge Systems. Case study analysis highlights best practices, while policy reviews examine institutional and technological advancements. Future recommendations focus on integrating digital tools and collaborative models to enhance participatory extension effectiveness.

Findings

Conceptual Framework of Participatory Approaches in Agricultural Extension

a) Definition and Evolution of Participatory Approaches: Participatory approaches in agricultural extension emphasize collaboration, shared decision-making, and farmer involvement alongside extension workers, researchers, and stakeholders. Unlike conventional models that treat farmers as passive recipients, these approaches recognize them as key contributors; ensuring innovations align with local needs (Olayemi *et al*., 2021) [41]. Traditional extension relied on a unidirectional technology-transfer model based on diffusion of innovations theory, often neglecting indigenous knowledge and agro-ecological diversity, leading to low adoption rates. The shift toward participatory extension emerged in response to these limitations, promoting inclusive decision-making through methodologies like Participatory Rural Appraisal (PRA), Participatory Technology Development (PTD), and Farmer Field Schools (FFS) in the 1970s and 1980s. These methods emphasized farmer-led experimentation, interactive learning, and practical farming experience. By the 1990s and early 2000s, development agencies and government programs institutionalized participatory extension, integrating digital tools and multi-stakeholder platforms to enhance collaboration in agricultural knowledge systems (Yang *et al*., 2023) [59].

b) Theoretical Foundations and Models of Participation in Extension: Participatory agricultural extension is rooted in development studies, rural sociology, and innovation systems theory. Participatory Action Research (PAR), developed by Freire and Lewin, advocates cyclical, collaborative knowledge generation involving impacted communities (Douthwaite & Hoffecker, 2017) [9]. The Farmer First Paradigm, introduced by Chambers, critiques top-down models, emphasizing farmer-driven learning and localized adaptation (Letty *et al*., 2012) [27]. The Agricultural Knowledge and Information Systems (AKIS) framework highlights interactive knowledge exchange among farmers, researchers, and policymakers rather than a linear transfer model. Several participatory models have emerged based on these theories (Leach & Mearns, 1996) [26]. The FFS model, established by the FAO, follows experiential learning through hands-on experiments, peer discussions, and group-based decision-making. PRA employs visual tools like mapping for community-led planning, while PTD fosters direct collaboration between farmers and researchers to co-develop locally adapted solutions. Community-based extension models further leverage cooperatives and grassroots organizations to facilitate agricultural learning and resource-sharing.

c) Principles of Participatory Extension Approaches: Participatory extension is founded on farmer empowerment, ensuring rural communities actively shape their agricultural development rather than relying on expert-driven knowledge transfer (Hagmann *et al*., 1999) [14]. Experiential and social learning encourage farmers to assess conditions, experiment, and develop solutions based on practical knowledge. Inclusivity and equity are key principles, ensuring smallholder farmers, women, and marginalized groups actively participate in decision-making (Cook *et al*., 2021) [8]. Traditional extension often overlooked women's contributions, whereas participatory methods integrate gender-sensitive approaches to leverage their agricultural expertise. Additionally, participatory extension prioritizes context-specific knowledge, promoting locally adapted practices over standardized solutions. Collective action and networking strengthen knowledge exchange, facilitating farmer-to-farmer learning through cooperatives and community organizations (Monge *et al*., 2008) [37]. Unlike conventional approaches focused on immediate productivity gains, participatory extension promotes sustainability and resilience through environmentally sound practices and climate adaptation strategies. Government-supported agencies and development frameworks, such as ATMA, have played a significant role in managing agricultural and rural workforce diversity (Vidyawati & Jadoun, 2025) [55].

Flexibility and adaptability further distinguish participatory models from rigid, expert-driven approaches (Gray *et al*., 2015) [13]. By emphasizing continuous learning and iterative feedback, these approaches enable farmers to refine technologies and practices in response to evolving conditions, ensuring long-term sustainability and resilience in agricultural systems.

Participatory Methods' Role in Agricultural Knowledge Production and Sharing

A. Farmer-Led Knowledge Sharing and Learning: Participatory extension draws attention to farmer-to-farmer knowledge sharing as opposed to the conventional top-down transfer (Singh *et al*., 2016) [47]. Traditional transfer-of-

technology (TOT) theories had posited a linear process of adoption, frequently neglecting farmers' experiential knowledge. Participatory methods, instead, prioritize interactive learning and support collaborative interaction between farmers, researchers, and extension workers towards developing practical solutions. Based on experiential learning and adult education, this method allows farmers to watch, try, and perfect their practices (Hainzer *et al*., 2022) [15]. Peer learning, through discussion, demonstration, and collaborative groups, has been found effective, particularly in limited-resource rural settings. Research indicates participatory knowledge-sharing improves technology adoption through the enhanced confidence and sense of ownership of innovations among farmers (Mapiye & Dzama, 2024) [32]. Contrary to top-down approaches that result in poor adoption rates, participatory extension makes innovations more adaptable and sustainable. Through using community networks and local institutions, this method builds on accessibility, relevance, and the sustainability of the long-term effects of agricultural development.

B. Collaborative Innovation Through Integration of Local and Scientific Knowledge: Participatory agricultural extension promotes innovation by integrating farmers' experiential knowledge with scientific inquiry to provide practical, culturally appropriate, and economically sustainable agricultural solutions (Meijer *et al*., 2015) [36]. In contrast to traditional models that apply externally generated technologies, participatory systems promote cooperation among farmers, scientists, and extension agents. Participatory Technology Development (PTD) facilitates collaborative experimentation, enabling farmers and researchers to experiment, improve, and modify technologies through successive learning. This makes innovations scientifically proven and locally appropriate. An example is participatory plant breeding (PPB), where breeders and farmers co-design crop varieties for particular agroecological settings (Swiderska *et al*., 2018) [51]. Participatory soil fertility management (PSFM) also combines traditional soil conservation practices with scientific nutrient approaches, enhancing soil health and sustainability.

In addition to technology, participatory innovation enhances institutional development in the form of farmer cooperatives, self-help groups, and community seed banks, ensuring sharing of resources and knowledge. They decrease dependence on external services and enable learning led by farmers. Through closing knowledge gaps and adding to local adaptive capacity, participatory practices enhance the resilience of farming communities (Klerkx *et al*., 2010) [19].

C. Contribution of Indigenous Knowledge to Participatory Agricultural Extension: Indigenous knowledge, gained over decades of farming experience, is the focus of participatory agricultural extension. In contrast to conventional models emphasizing scientific know-how, participatory methods combine indigenous knowledge in soil fertility, pest management, water conservation, seed choice, and climate adaptation. Participatory extension promotes co-production of knowledge by establishing avenues for farmer-initiated documentation, knowledge exchange, and interaction among traditional and scientific specialists. Resource management at the community level empowers farmers to develop climate-resilient land-use strategies, as in Africa and Latin American traditional agroforestry systems, which build climate resilience (Adeyanju *et al*., 2021) [2]. In spite of institutional inclinations in favor of scientific knowledge, participatory methods more and more certify and incorporate indigenous knowledge into extension systems. Involving both knowledge systems in participatory extension guarantees that farming innovations are scientifically valid, ecologically sustainable, and culturally acceptable.

D. Influence of Farmer Field Schools (FFS) on Learning Agricultural Sustainability: Farmer Field Schools (FFS) are successful participatory extension approaches that foster sustainable agricultural learning. Originally designed by the FAO for Integrated Pest Management (IPM) in rice cultivation, FFS has been scaled up to other agricultural sectors. Its underlying philosophy is experiential learning, where farmers participate in field activities, observations, and group discussions to acquire problem-solving and adaptive capacities (Tomlinson & Rhiney, 2018) [52]. In contrast to the conventional extension approaches with predetermined training sessions, FFS promotes trial and error by farmers, testing field conditions, and making data-driven decisions. This improves their knowledge of agro ecosystems, better managing pests, soil fertility, and climate resilience. Evidence indicates that FFS is associated with long-term knowledge retention, critical thinking, leadership, and participation in the community. It also scales up sustainable practices by means of farmer-to-farmer extension networks, creating peer-to-peer learning (Kalita *et al*., 2019) [21]. By improving farmers' capacity to develop and use knowledge, FFS enhances participatory extension and guarantees sustainable agricultural systems. Capacity-building initiatives, such as smart agricultural training under NMAET and ATMA, are crucial for addressing the cultural gap and enhancing adaptation in rural economies (Vidyawati & Jadoun, 2025) [56].

Participatory Methods in Agricultural Extension: Approaches and Tools

A. Participatory Rural Appraisal (PRA) Techniques in Extension Work: Participatory Rural Appraisal (PRA) is an inclusive approach in agricultural extension that engages farmers in decision-making and problem-solving. Emerging in the 1980s, PRA evolved from Rapid Rural Appraisal (RRA), shifting to a farmer-centered model that values local knowledge (Maskrey *et al*., 2022) [30]. Key PRA techniques include participatory mapping, transect walks, seasonal calendars, matrix ranking, Venn diagrams, and livelihood analysis. These tools aid collective learning, enabling farmers to analyze farming challenges and develop solutions. For instance, participatory mapping helps visualize land use, while transect walks provide real-time field insights (Mengistu *et al*., 2022) [34]. PRA-based services enhance technology adoption, social learning, and community resilience. However, challenges such as facilitator bias and the need for skilled practitioners highlight the need for continuous training (Kitson *et al*., 2008) [18].

B. Farmer-Led Research and On-Farm Trials for Technology Testing: Farmer experimentation and on-farm trials engage farmers in experimental testing and experimenting with agricultural technology under actual circumstances,

making the technologies relevant to local practices. Based on Participatory Technology Development (PTD), this system facilitates continuous farmers', extension worker's, and researchers' feedback (Toffolini *et al*., 2022) [53]. On-farm experiments test new crops, soil fertility methods, pest's management, and water conservation techniques. Participatory Varietal Selection (PVS) enables farmers to assess the performance and adaptation of crops. African, Asian, and Latin American case studies illustrate the effectiveness of farmer-led research in increasing technology adoption and resilience. For instance, participatory soil fertility trials in Malawi enhanced nutrient management, while pest management research in Southeast Asia minimized pesticide use through community-based Integrated Pest Management (IPM) programs.

C. Workshops, Focus Group Discussions and Knowledge-Sharing Platforms: Workshops, focus group discussions (FGDs), and online platforms enable participatory problem-solving, information sharing, and decision-making in agricultural extension. FGDs congregate farmers, extension agents, and researchers to evaluate challenges and formulate solutions through interactive discussions (Mulema *et al*., 2016) [38]. Workshops, which are typically employed in Farmer Field Schools (FFS), are applied hands-on for topics such as value chain development and soil conservation, usually combining participatory video methods. Digital technologies, such as online forums, mobile-based advisory services, and community radio, facilitate remote interaction and immediate exchange of knowledge, overcoming geographic and linguistic divides (Khan *et al*., 2025) [22].

D. Role of Digital Technologies and ICTs in Strengthening Participation: Information and communications technologies and digital technologies have transformed participatory extension through enhancing information sharing and farmers' empowerment. Technologies such as mobile platforms, SMS-based advice, and online networks bring extension agents, farmers, and markets together with less transactional cost. Others include Digital Green, e-Choupal, and M-Kilimo information dissemination and decision platforms. Geospatial mapping and remote sensing enable farmers to keep track of soil conditions and climatic changes (Mathenge *et al*., 2022) [33]. Yet, digital literacy deficits, linguistic barriers, and restricted access to the internet continue to be major obstacles to ICT uptake. Recent trends in HRM emphasize not only technological integration but also grassroots-level training and sustainability, as observed in ATMA initiatives (Vidyawati *et al*., 2025) [57].

E. Gender-Sensitive Participatory Approaches in Agricultural Extension: Gender-sensitive participatory extension guarantees active women participation in farm decision-making and technology uptake. The conventional extension approaches have been exclusionary against women because of socio-cultural impediments, but participatory approaches, such as women participation in Farmer Field Schools and community networks, are inclusive. Such approaches have boosted climate-smart agriculture, nutrition-sensitive agriculture, and micro-enterprise initiatives. Mobile advisory services that are specially designed for women in India and Africa have also improved agricultural knowledge and resource access (Lahiri *et al*., 2024) [24].

Impact of Participatory Extension on Enhancing Sustainable Farming Practices

A. Scaling Up Climate-Resilient Agriculture Through Participatory Means

Participatory extension agriculture promotes climate-resilient agriculture through the blending of farmer experience and scientific evidence. Climate-smart agriculture (CSA) will increase productivity, resilience, and reduce emissions, but conventional extension tends to neglect local agro-ecological heterogeneity. Participatory approaches such as Farmer Field Schools (FFS) and Participatory Rural Appraisal (PRA) allow farmers to develop climate-resilient technologies themselves (Paparrizos *et al*., 2021) [43].

Some of the notable contributions include dissemination of drought and flood-tolerant crop varieties using participatory plant breeding (PPB) and promotion of adaptive soil and water conservation practices such as agroforestry and rainwater harvesting. Also, participatory extension enhances availability of climate information services through mobile-based platforms and community weather systems, facilitating well-informed decision-making (Caine *et al*., 2015) [5]. Successful adoption of participatory CSA testifies to farmer involvement in sustainable agriculture innovations.

B. Sustainable Soil and Water Conservation through Collective Action

Participatory extension promotes sustainable soil and water management (SSWM) by supporting farmer-led experimentation and collective action. Unlike traditional models, it addresses solutions to local agro-ecological problems. Participatory watershed management improves soil fertility, groundwater recharge, and erosion control through community-based methods such as terracing and contour farming (Meetei & Tsopoe, 2024) [35].

Furthermore, participatory methods encourage organic soil fertility management practices like composting, green manure, and crop residue, decreasing reliance on inorganic fertilizers and improving soil health. By integrating indigenous knowledge with scientific knowledge, participatory extension enhances regenerative agriculture and community resilience to environmental threats.

Case Studies of Successful Participatory Agricultural Extension Models

A. Farmer-Led Extension Programs in Varied Agroecological Areas: Farmer extension initiatives provide a grassroots peer-to-peer knowledge-sharing alternative, supporting locally driven innovation within varied agroecological ecosystems (Osumba *et al*., 2021) [42]. Farmers are empowered through these models as community leaders for agricultural learning and adaptation. Within East Africa, the Farmer Trainers Approach makes it possible for experienced farmers to carry out farmer training and experiments on their land. Likewise, India's Self-Employed Women's Association (SEWA) supports women farmer-to-farmer knowledge sharing in market access and sustainable agriculture. Evidence shows that such programs enhance knowledge retention, speed up technology uptake, and enhance community resilience (Ensor & de Bruin, 2022) [10].

B. Participatory Technology Development in Low-Resource Farming Systems: Participatory Technology Development (PTD) allows poor farmers to co-create and validate innovations appropriate to their agroecological and socio-economic conditions. In contrast to top-down research approaches, PTD combines scientific knowledge with farmers' knowledge to develop solutions adapted to their conditions. Participatory Varietal Selection (PVS) in West Africa has improved food security by enabling the use of stress-tolerant millet and sorghum varieties (Azevedo *et al*., 2019) [3]. In Kenya and Ethiopia, pastoralist societies have collectively developed disease management and rangeland rehabilitation methods to enhance livestock sustainability. The success of PTD highlights the potential of participatory research in supporting farmer-led innovations.

C. Effect of Community-Based Organizations and Cooperatives in Agricultural Extension: Cooperatives and Community-Based Organizations (CBOs) strengthen participatory agricultural extension through collective decision-making, mobilization of resources, and joint action. These agencies offer training access, financial services, and input supply networks, solidifying the capacity of farmers for sustainability. Kenyan dairy cooperatives advance training on fodder management and dairy hygiene, while Latin American coffee cooperatives promote organic farming uptake and access to markets (Sirdey *et al*., 2020) [48]. By enhancing social capital and the exchange of knowledge, CBOs and cooperatives have diversified participatory extension services for increased livelihood and sustainability.

D. Participatory Methods in Precision Farming and Intelligent Farming: Participatory extension in precision agriculture guarantees digital innovations like remote sensing and GIS mapping to meet the requirements of smallholder farmers. Farmers in Andhra Pradesh utilize mobile apps for weather conditions, soil condition information, and pest monitoring, whereas in Brazil, participatory precision agriculture streamlines fertilizer application and irrigation scheduling (Lakhiar *et al*., 2024) [25]. These efforts prove how participatory methods improve farm management, sustainability, and access to modern technologies.

Challenges in Implementing Participatory Agricultural Extension Approaches

A. Institutional and Policy Challenges: Institutional and policy challenges prevent the effective implementation of participatory agricultural extension. Most national systems continue to follow top-down, centralized models focusing more on production targets than farmer participation, restraining decentralized and farmer-led approaches (Felt *et al*., 2007) [12]. A central challenge lies in the lack of coherent policies underpinning participatory extension, since agricultural development tends to favour standardized technology transfer over differentiated smallholder needs. Moreover, power inequalities among extension agents, researchers, and farmers result in resistance to sharing knowledge. Fragmented policies and weak inter-sectoral coordination further discourage participatory action, and local governments often lack the appropriate resources and technical skills to roll out such programs efficiently.

B. Socio-Cultural and Economic Barriers: Socio-cultural and economic aspects play an important role in participatory agricultural extension. Power dynamics and cultural norms, especially in patriarchal systems, tend to disengage women farmers from active participation in extension services (Qureshi *et al*., 2018) [45]. Trust in outside intervention is also a concern since past adverse experiences with inappropriate or unsustainable extension schemes make farmers wary. Financial restrictions, such as financial instability, limited credit availability, and market volatilities, render it challenging for poor farmers to devote time and resources to participatory activities, particularly when they are required to contribute financially or in terms of labor (Prain *et al*., 2020) [44].

C. Funding and Resource Constraints: Inconsistent and limited funding is one of the biggest challenges to participatory extension programs, which involve long-term investment in facilitation, training, and monitoring. In contrast to conventional extension models that are based on government subsidies, participatory methods require consistent financial support, but short-term donor funding cycles frequently result in program discontinuity (Mansuri & Rao, 2012) [29]. Moreover, donor agencies focus more on short-term outcomes, such as yield increases or technology adoption rates, than on long-term participatory processes empowering farmers. Infrastructure issues, such as poor transportation, communication networks, and logistical problems, also hamper participatory extension efforts. High costs of transactions, including the employment of facilitators and the arrangement of field-based learning activities, contribute to resource constraints.

D. Capacity Building and Training Gaps among Extension Workers: Participatory extension depends on skilled extension agents who can effectively support farmer-led learning. However, many extension workers are primarily trained in traditional, top-down knowledge dissemination methods, which do not align with participatory facilitation techniques (Voinov *et al*., 2016) [58]. Agricultural education often emphasizes technical expertise rather than interactive farmer engagement strategies, leaving extension personnel unprepared for collaborative learning environments. Additionally, structured in-service training programs aimed at enhancing participatory skills are limited, restricting the capacity of extension staff to facilitate effective knowledge exchange.

E. Challenges in Technology Adoption and Resistance to Change:

Farmers often exhibit reluctance toward adopting new agricultural practices due to various factors, including risk perception, cultural adherence to traditional methods, and previous experiences with extension services (Nettle *et al*., 2022) [40]. Since participatory extension introduces innovative technologies that require behavioral shifts, some farmers may hesitate to embrace these changes. Social dynamics, such as peer influence and collective decision-making within farming communities, further impact adoption rates (Chow & Chan, 2008) [6]. Economic uncertainties, such as fluctuating yields or high input costs, also deter farmers from experimenting with unfamiliar practices. To address these barriers, participatory extension initiatives should integrate adaptive learning approaches and risk-mitigation strategies to build farmer

confidence and encourage a gradual transition to new technologies.

Strategies for Enhancing Participatory Strategies in Agricultural Extension

A. Policy Reforms to Support Participatory Extension: Successful policy reforms are necessary for transforming agricultural extension from top-down systems to participatory methods that empower farmers (Mapiye & Dzama, 2024) [32]. Decentralization allows localized decision-making but needs capacity-building policies to empower local governments, extension agents, and farmer organizations. Consistent financial support is also important, including specific funding for participatory research, farmer-managed programs, and knowledge exchange platforms. Furthermore, policies that encourage farmer engagement, like subsidies for community-led extension services, can promote participation (Agwu *et al*., 2023) [1].

B. Strengthening Public-Private Partnerships (PPP) Public-private partnerships (PPPs) enhance participatory extension by linking public institutions' coverage with private-sector skills. Government extension services are usually under-resourced, but agribusinesses, NGOs, and cooperatives play roles in training, market access, and technology diffusion. Effective PPP models are found in India's e-Choupal program, which combines participatory digital advisory services, and sub-Saharan Africa partnerships that allow participatory varietal selection (Khare *et al*., 2011) [20]. But the regulatory systems have to guarantee that private-sector engagement does not come at the expense of accessibility or inclusiveness for smallholder farmers.

C. Capacity Development for Extension Agent and Farmer Leadership: The shift to participatory extension necessitates the training of extension agents in facilitation, participatory learning, and community outreach skills (Lukuyu *et al*., 2012) [28]. Farmer leaders should also undergo skill development through Training-of-Trainers (ToT) programs and Farmer Field Schools (FFS), which have been shown effective in knowledge-sharing in Asia and Africa. Mentoring networks linking experienced farmers with extension agents can also encourage learning from each other and support innovations led by farmers.

D. Leveraging Digital Technologies for Participatory Knowledge Sharing: Digital technologies have revolutionized agricultural extension by making it possible to exchange knowledge in real-time. Mobile-based advisory services, participatory mapping, and social media sites enable farmer-to-farmer learning, while participatory videos and community radio enable the sharing of local knowledge in remote communities (Naika *et al*., 2021) [39]. Crowd sourced data platforms also support decision-making by enabling farmers to exchange real-time information on climate, pest outbreaks, and soil health.

E. Fostering Multi-Stakeholder Partnerships Participatory extension is made robust by a collaborative process that includes farmers, researchers, policymakers, NGOs, and private sector actors. Multi-stakeholder innovation platforms (MSIPs) provide the platform for interactions, co-development of extension plans, and policy interaction (Barletti *et al*., 2020). Effective projects, like participatory research alliances and community-based extension networks, keep extension services farmer-centric and locally responsive to agriculture problems.

Future Directions and Emerging Trends in Participatory Agricultural Extension

A. AI and Big Data in Participatory Decision-Making: Big data and AI are transforming participatory agricultural extension through enabling real-time decision-making, predictive analytics, and personalized advisory services. Multilingual, voice-based chatbots based on natural language processing improve accessibility. Big data applications such as precision agriculture and climate forecasting enable data-informed community decisions. But data privacy, ownership, and digital equity issues need to be tackled to ensure inclusive uptake (Jamba & Marambi, 2024) [17].

B. Farmer-Led Innovation Networks: Future extension models will prioritize farmer-initiated innovation networks that develop peer-to-peer learning and bottom-up experimentation to build agricultural resilience, especially in climate-exposed areas.

C. Climate Resilience and Participatory Adaptation Participatory extension will more and more incorporate climate-smart technology, disaster risk reduction, and community-led climate forecasting to enable adaptation by smallholder farmers to climate variability.

D. Community-Based Agroforestry and Sustainable Land Management: Farmer-managed agroforestry and sustainable land management activities will prioritize biodiversity conservation, planting of trees, and regenerative farming, addressing deforestation and land degradation (Isaac *et al*., 2024) [16].

E. Market Linkages and Value Chain Development Extension through participatory approaches will extend to cover market access, value chain linkage, and farmer entrepreneurship. Building cooperative capacity, promoting participatory certification and the use of digital platforms will add economic sustainability.

Conclusion

Participatory extension agriculture has become a revolutionary strategy for closing knowledge gaps and developing sustainable agriculture. In contrast to conventional top-down extension systems, participatory approaches position farmers at the forefront of knowledge generation, encouraging interactive learning, localized solutions, and community-led innovations. Through the use of methods like Farmer Field Schools (FFS), Participatory Rural Appraisal (PRA), and online advisory platforms, participatory extension supports the uptake of climate-smart agriculture, improves farmer resilience, and enhances social equity, including the engagement of marginalized groups like women and smallholder farmers. In spite of its established advantages, the mass scale-up of participatory extension is confronted with various challenges such as institutional inertia, budget limitations, and resistance to change. Overcoming these hindrances demands more robust policy structures, increased investment in training extension workers, and the use of digital technologies to enable

knowledge sharing and real-time decision-making. Enhancing public-private partnerships and promoting multi-stakeholder collaboration can also make participatory extension programs more effective and scalable.

In the future, participatory extension will be influenced by innovation in artificial intelligence, precision agriculture, and evidence-based decision-making. While incorporating these technologies, it is essential to maintain the fundamental values of farmer empowerment, learning by doing, and sustainability. Through constant innovation and improvement in response to new agricultural issues, participatory extension can become a strong driver of resilient, inclusive, and sustainable agricultural systems, ultimately benefiting global food security and rural development.

Practical Implications: Participatory methods of agricultural extension have important practical effects on sustainable agriculture. Through engaging farmers in active co-creation of knowledge, participatory methods improve decision-making, resulting in increased adoption rates of sustainable agricultural practices. Integration of local and scientific knowledge improves innovation, which ensures that new technologies are aligned with farmers' requirements and agroecological contexts. Gender-sensitive participatory models empower women through enhanced access to agricultural training and decision-making positions. Moreover, extension through participation enhances climate adaptation through the implementation of climate-smart agriculture like drought-tolerant crops, agroforestry, and water conservation. Digital platforms like mobile advisory services and social media enhance real-time knowledge sharing, enhancing access to agricultural knowledge. Farmers' field schools and cooperatives are examples of community-led initiatives that promote collective effort toward soil and water conservation, resulting in better resource management and environmental sustainability in the long run. Policymakers can utilize participatory models to craft farmer-oriented agricultural policy that caters to decentralized extension services and multi-stakeholder partnerships. Contributing to innovation, inclusivity, and sustainability, participatory extension promotes agricultural productivity, resilience, and rural livelihoods, positioning it as an important strategy for contemporary agricultural development.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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