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# Women networks in India- a potential pathway for sustainable seed production and dissemination of climate resilient crop varieties

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**Introduction:** The modern breeding technologies have led to developing a number of crop varieties in India, however, there has been continuous challenge for the farmers and particularly women to access the seeds of the improved and climate resilient varieties. Dissemination of quality seeds of improved varieties can potentially enhance productivity, food security and livelihoods, while fostering resilience to environmental challenges. The study was intended to evaluate the role of women collectives called self-help groups (SHGs) for increasing the access to quality seeds of climate resilient varieties of rice and wheat, and measure agricultural production outcomes.

**Methods:** Exploiting the potential of women-led SHGs as an alternative seed production and distribution pathway, a randomised experiment was conducted to assess the role of SHGs for scaling the adoption of improved varieties. To assess the outcomes on seed access, supply and dissemination, and their implications on socio-economic well-being, data was collected through baseline, midline, and endline surveys conducted in four districts across Indo-Gangetic plains in India.

**Results and discussion:** The results demonstrate that SHG households adopted seeds of improved crop varieties at significantly higher rates than non-SHG households, with adoption increasing from about 15% at baseline to nearly 50% by endline among SHG households. Considerably, higher percentage of SHG farmers sourced seed through community seed enterprises associated with the SHGs, leading to a decrease in the seed costs and dependence on agri-input dealers for seed purchase. The magnitude of seed production and supply was significantly higher in villages where SHGs participated in seed production, recording more than a 200% increase in seed output over the study period compared to control villages. Consequently, SHG households that produced seeds and adopted improved varieties achieved substantially higher agricultural productivity, with rice and wheat yields increasing by approximately 28% and 25%, respectively, relative to control households. The collective approach for seed entrepreneurship enhanced the economic status of SHGs and their members in addition to ensuring the sustainability and scalability of seed production business. Besides, the SHG-based models can serve as a scalable and sustainable solution for addressing systemic challenges in seed systems, fostering inclusive agricultural development, and advancing gender equity in rural economies.

## KEYWORDS

improved crop varieties, randomized experiment, sustainable seed systems, women empowerment, women-led self-help groups (SHGs)

## Highlights

- Developing sustainable practices for seed production, leading to enhanced distribution of climate-resilient crop varieties.
- Resulting in the reduction of seed costs and dependence on agri-input dealers for seed purchase.
- Achieving higher crop yields and overall agricultural productivity, enhancing food security.
- Empowering rural women via SHGs, significantly boosting their role in sustainable seed production and delivery.

## 1 Introduction

Agriculture serves as an important pillar of the Indian economy, contributing approximately 18% to the nation's GDP and supporting the livelihoods of over half the population (Government of India, 2023). In the rural expanses of India, where poverty remains predominant and infrastructure development lags, agricultural productivity serves as a vital determinant of household well-being and food security (World Bank, 2018). Smallholder farmers in particular face multifaceted challenges, including low crop yields, obsolete farming practices, inadequate access to markets and low availability of quality inputs (FAO, 2021). Among the various challenges, the low availability of quality seeds is one of the major factors limiting agricultural productivity in the country (Kumar A. et al., 2021; Matuschke and Qaim, 2009). High-quality seeds of improved crop varieties are widely recognized as crucial for increasing agricultural output, as they have a direct impact on crop resilience, performance and overall productivity (McGuire and Sperling, 2016).

Uttar Pradesh, heart of Indo-Gangetic plains, has a significant proportion of farmers depending on traditional and informal seed systems that are often inefficient and characterized by the local exchange of seeds (Zaidi et al., 2018). These systems frequently suffer from serious drawbacks, such as poor seed quality and varietal purity, low germination rates, and high susceptibility to pests and diseases (Pal, 2018). Despite governmental initiatives aimed at promoting certified seeds, many smallholder farmers remain adamant to the informal seed sector, primarily due to challenges related to affordability, availability and awareness (Dar et al., 2021; Kumar et al., 2020). Beyond issues of availability and affordability of quality seeds, limited reach and effectiveness of formal agricultural extension systems remain a critical constraint, particularly for small holder farmers. Consequently, the urgent need arises for innovative strategies to enhance seed access while effectually addressing the socio-economic barriers faced by smallholder farmers, particularly women. Besides, public extension services in India are often overstretched and predominantly oriented towards male farmers, resulting in inadequate dissemination of improved technologies among women and marginal farming households. In this context, women-led Self-Help Groups (SHGs) offer a promising community-based extension pathway by enabling peer-to-peer learning, collective action, and localized dissemination of agricultural knowledge and inputs. Acting as informal yet effective extension agents, SHGs facilitate the diffusion of improved crop varieties, seed production practices, and climate-resilient technologies through trust-based social networks at the village level.

We conducted a study on a project designed to uplift the informal seed sector through a community-driven models funded by Bill & Melinda Gates Foundation (BMGF) to Rajiv Gandhi Mahila Vikas Pariyojana (RGMVP). This project aimed to exploit the potential of Self-Help Groups (SHGs) for improving the access to high-quality seeds and empower women in agricultural households. SHGs as community-based organizations can smoothen the collective engagement of women in a range of financial, social and agricultural activities (Hossain et al., 2024). By centering women in this initiative, the program seeks not only to enhance seed availability and quality, but has the potential to amplify women's roles in agricultural decision-making, thereby promoting greater gender equality within rural communities (Dar et al., 2020).

Implemented across four districts of Uttar Pradesh, the study adopted a rigorous phased approach that began with a comprehensive baseline survey to evaluate existing conditions, followed by a midline and the endline surveys to assess longitudinal impacts. The initial survey uncovered critical gaps in seed access, revealing that most farmers relied on low-quality saved seeds, with female farmers notably sidelined in the seed selection process (Dar et al., 2020), and accessing the seeds recommended by the local dealers at very high costs. The interventions included training SHG members in seed production and storage processes, while simultaneously strengthening their access to early generation seeds by linking them with formal seed system. Besides, the initiative sought to enhance awareness about the benefits of using quality seeds and empower women to assume decision making roles in agricultural practices, including seed management and distribution.

This study presents an in-depth analysis of the treatment outcomes, revealing critical insights into how SHGs can be deployed to enhance seed access, improve agricultural yields and promote gender empowerment. The study further explores the spillover effects of the treatments, extended beyond immediate participants to neighboring communities to assess the broader agricultural and social progress (Dar et al., 2018). This underlines the transformative potential of community-driven approaches in reshaping rural agricultural landscapes.

Aligned with the Sustainable Development Goals (SDGs), particularly Goals 1 (No Poverty) (Zero Hunger) and 5 (Gender Equality), this research highlights the potential of community-based seed systems in advancing food security and gender equity within rural India. By placing women at the core of the interventions in the project, this study aims to generate evidence for established pathways to enhance agricultural productivity, while concurrently empowering rural women to actively engage in decision-making processes. The findings of this study hold crucial inferences for policymakers and development practitioners aiming to identify scalable models that address the intertwined challenges of low productivity, seed insecurity and gender inequality, prevalent in the farming sector. Several studies from India have highlighted the role of women-led collectives, SHGs, and farmer groups in improving technology adoption, seed access, and agricultural outcomes through collective action and peer learning. Evidence suggests that group-based approaches can function as effective decentralized extension platforms, particularly for disseminating improved and climate-resilient crop varieties and strengthening informal seed systems (Beuchelt and Badstue, 2013; Dar et al., 2020; Hossain et al., 2024). However, rigorous experimental evidence quantifying the impact of women-led groups on seed production, dissemination and productivity outcomes remains

limited. This study provides empirical evidence on the effectiveness of women-led SHGs as a community-based extension and seed system intervention in the Indo-Gangetic Plains.

## 2 Methodology

### 2.1 Research design and location

Rajiv Gandhi Mahila Vikas Pariyojana (RGMVP) implemented a project to strengthen the informal seed sector in Indian state of Uttar Pradesh with the support of Bill & Melinda Gates Foundation. The project deployed women-led Self-Help Groups (SHGs) to increase farmers' access to high-quality seeds, with the goal of improving agricultural productivity, empowering women and enhancing nutritional outcomes. The interventions focused on capacity-building through elaborated trainings on quality seed production, processing and distribution, making high-quality seeds locally accessible and affordable. By decentralizing seed production and empowering women farmers, the project aimed to reduce dependency on commercial seed dealers for the improved and climate resilient varieties, while enhancing agricultural resilience. The project introduced Sahbhagi Dhan, a drought tolerant rice variety to enhance the sustainability in crop production. Besides, the treatment SHGs were trained in improved agricultural practices, including seed treatment, proper planting techniques and post-harvest management.

The study was conducted across four districts viz.; Amethi, Lucknow, Raebareli and Unnao in central part of the state, encompassing seven blocks, specifically targeting areas characterized by a predominant rice-wheat cropping system. These districts represent the central Indo-Gangetic Plains, characterized by recurrent drought and water-stress conditions, and a high reliance on informal seed systems. The strong presence of women-led Self-Help Groups (SHGs) supported by RGMVP provided an appropriate setting to assess SHGs as a community-based extension and seed dissemination mechanism.

We conducted rigorous evaluation method in the form of a Randomized Control Trial (RCT) to evaluate the causal impact of the interventions. The study involves households in both treatment and control groups, with the randomization of gram panchayats (GPs) into these groups to ensure unbiased estimates of the measurable impact. The impact evaluation is centered on a two-stage randomized design. In the first stage, gram panchayats (GPs) were randomly assigned to the treatment group, where the project was implemented, and the control group, where the project was not introduced. The purpose of this randomization is to compare the outcomes in GPs with and without the interventions, and thus identify its effects. The second stage of randomization was conducted within the treatment GPs. Households were either randomly selected to receive the intervention or left out as part of a control group within treatment GPs. This allows the study to examine both the direct impacts on the SHG households that received treatment and the potential spillover effects on SHG and non-SHG households that did not receive direct intervention.

### 2.2 Experimental groups

The households in the experiment can be classified into 5 groups (Figure 1). The experimental design allows for three important

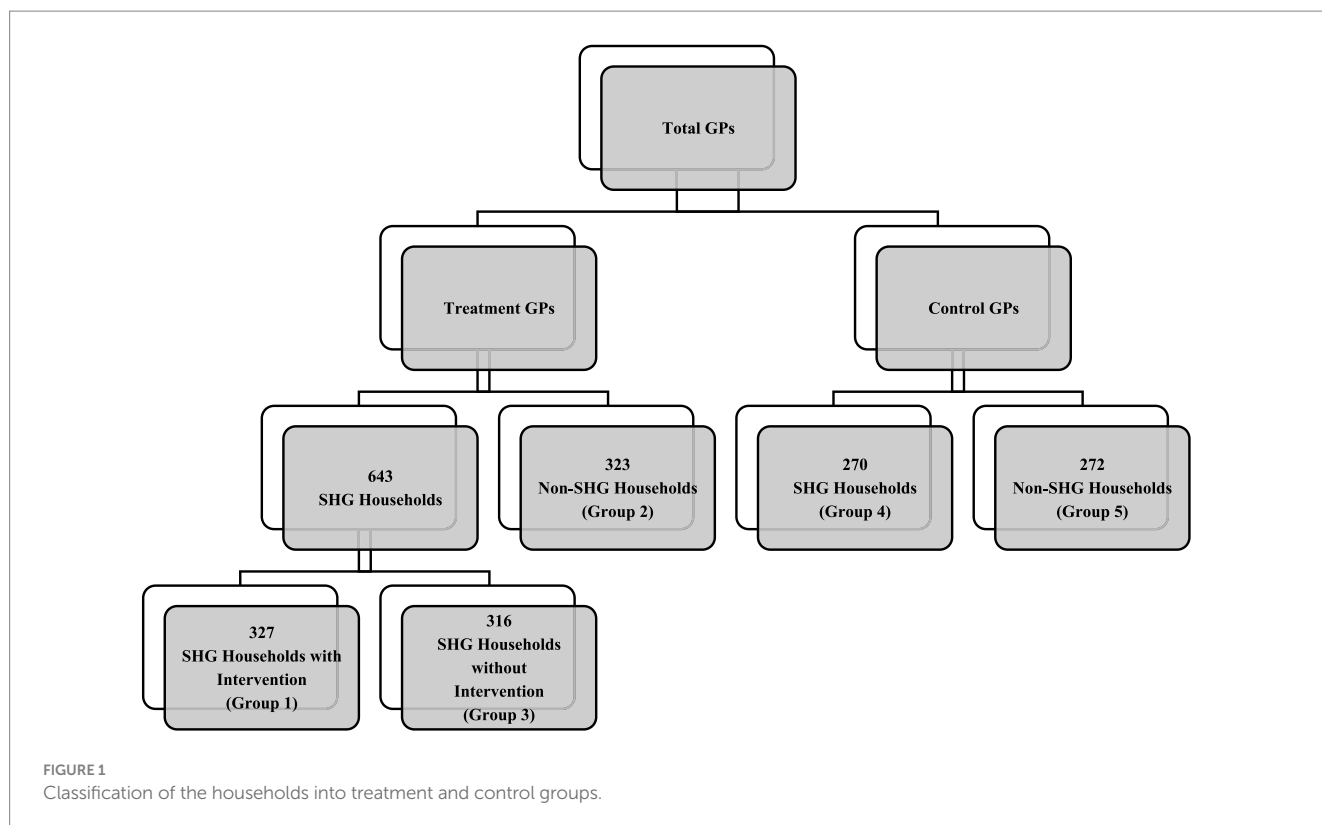
parameters to be estimated. First, comparing groups 1 and 4 allows for direct estimation of the impact of the intervention on SHG households. Second, comparing groups 3 and 4 delivers an estimate of whether the intervention had spillover impacts on other SHG households that were not direct participants. Finally, comparing groups 2 and 5 measures whether the intervention had any indirect benefits on non-SHG households within the treatment GPs. As RGMVP planned to expand its model both vertically (expanding SHG model) as well as horizontally (spreading message to non-SHGs in the operational area), it was important to consider the comparison of groups 3 and 4, and groups 2 and 5 as well.

### 2.3 Sampling and data collection

The sampling followed a multi-stage procedure. First, four districts were purposively selected. Within each district, blocks with an active presence of RGMVP-supported women-led SHGs were identified. From these blocks, gram panchayats (villages) were randomly selected and assigned to treatment and control groups as part of the randomized experimental design. In the final stage, households were randomly selected from SHG and non-SHG lists within the selected villages. The baseline sample size of 1,508 households was determined to ensure adequate statistical power to detect meaningful differences between treatment and control groups, accounting for multiple experimental arms and potential attrition across survey rounds.

The experimental design generated the treatment and control groups that were approximately similar on observable characteristics measured at the time of baseline survey. Therefore, the impact of the program can be credibly measured by using simple comparisons of outcomes across treatment and control groups. Baseline survey was carried out in April and May 2016, prior to the project implementation. The survey covered several modules, including existing socio-economic characteristics, cropping patterns, seed procurement practices, agricultural inputs, crop yields, household assets, and decision-making roles. Households in the experimental sample were quite poor with average incomes per capita around 39 rupees per day, and less than 60 percent of households having access to electricity. The geographical distribution of households was recorded using GIS mapping to ensure accuracy in data collection (Figure 2).

The baseline data were rigorously tested for balance across treatment and control groups to validate the success of the randomization. Baseline balance was assessed by comparing key socio-economic and agricultural characteristics, across treatment and control groups using t-tests and chi-square tests, as appropriate. The results confirmed no statistically significant differences at baseline (Supplementary Tables S1–S3). This ensured that any observed impact could be attributed to the interventions and not to pre-existing differences between the groups. Each module was structured to capture comprehensive baseline data for future comparison with midline and endline surveys. The interventions were implemented in Kharif 2016, just after the completion of baseline survey. The midline survey was conducted in late 2017, focusing on the Rabi 2016 and Kharif 2017 cropping practices. This survey was conducted with 1,000 households randomly selected from the five groups, with 200 households from each group. The final (endline) survey was conducted in 2019, which reviewed the Kharif 2018 and Rabi 2018 cropping cycles, evaluating 955 households due to missing responses across the experimental



groups. Data collection during all the surveys was carried out through structured questionnaires administered to the selected households. The midline and endline surveys included questions on agricultural practices, seed sources, training participation, crop yields, and knowledge of improved seed varieties. The endline survey also incorporated questions to assess changes in practices and outcomes since the midline survey.

## 2.4 Impact evaluation

The impact evaluation was based on comparisons between the five groups using a difference-in-differences approach, which compares changes in outcomes over time between the treatment and control groups. The analysis focused on several key areas:

### 2.4.1 Participation in trainings

The intervention offered a range of trainings to SHG members, focusing primarily on seed production as part of the project. One component of these training sessions was to encourage participant households to take part in additional trainings related to agriculture and crop production. The surveys measured participation in these trainings across the five groups and assessed the extent to which the project increased participation in trainings other than intervention.

### 2.4.2 Seed production and varietal adoption

The key objective of the project was to increase the seed production and adoption of improved crop varieties through SHGs. The surveys documented the seed production and adoption rates of improved varieties, and whether the interventions influenced seed

sourcing behavior, such as obtaining seeds from SHGs instead of agro-dealers.

### 2.4.3 Agricultural production and profitability

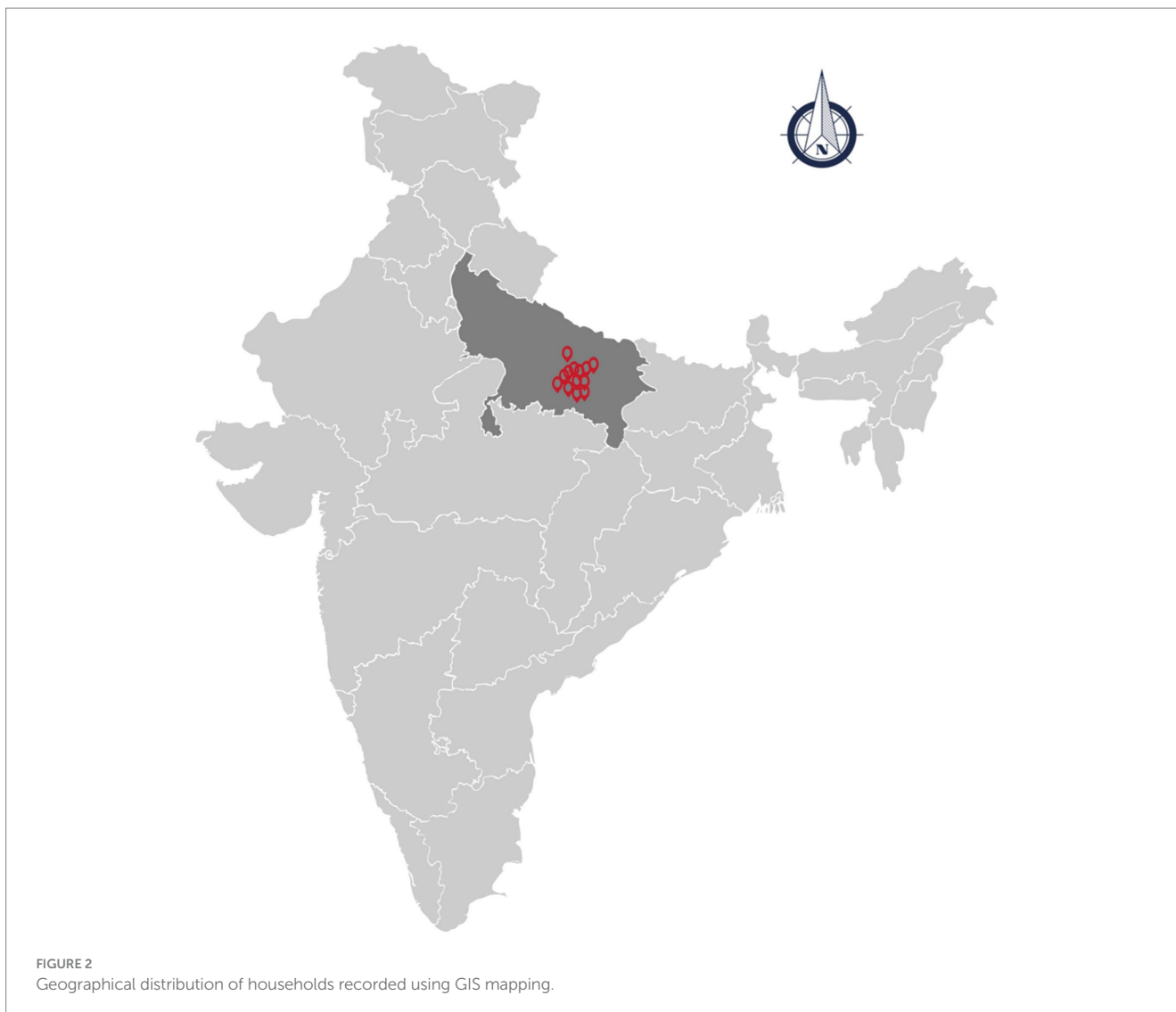
The study evaluated the project's effects on rice and wheat yields, total agricultural output, and household productivity. The midline and endline surveys collected detailed production data, allowing for an analysis of whether the program led to increases in productivity and income.

### 2.4.4 Indirect and spillover effects

The study examined whether SHG households that were not directly participating in the intervention, as well as non-SHG households in treatment GPs, experienced any indirect benefits from the project activities, such as increased access to seed of improved crop varieties or trainings. Besides, spillover effects on control GPs were also assessed.

## 2.5 Data analysis

The data from the baseline survey was analyzed using descriptive statistics to summarize the key characteristics of the households in the sample. Comparative analysis across treatment and control groups was performed to assess the baseline balance. During subsequent surveys, sample statistics were calculated for each of the five experimental groups. For each outcome, the analysis compared the results for treatment households with those for control households, both SHG and non-SHG. These comparisons were used to assess both the direct effects of the interventions on participating households and any indirect effects on non-participants within the



treatment GPs. A positive difference between the comparison groups was considered an impact, based on the assumption of no initial difference. Differences between the comparison groups were further tested for significance using Chi-square test of association and Z-test for difference in proportions. Data was processed using IBM SPSS software. There were cases with missing response for multiple variables. Such cases were either completely discarded or retained for analysis of those set of variables for which responses were successfully recorded. Therefore, while analysis of data on rice crop/seed is based on information from nearly 1,000 respondents, study of other aspects is derived from answers of 955 respondents.

### 3 Results

The evaluation of the project interventions reveals significant insights into its impact on participation in trainings, seed production and supply, adoption of improved varieties, and overall agricultural outcomes. Data collected from baseline, midline, and endline surveys across the experimental groups provide a comprehensive view of the effectiveness of the treatments.

#### 3.1 Training program participation and impact

At the baseline, the reach of trainings was limited, with only 20% of households in Group 1 and 15% in Group 3 reporting participation in the agriculture related trainings. The data shows low initial engagement and limited awareness of the trainings' potential benefits. By the midline, the project has made notable progress in increasing the participation. Group 1 saw a significant rise to 45%, reflecting increased outreach and improved communication strategies. Group 3 also showed a substantial increase to 35%, while Group 2 and Group 4 exhibited moderate increases to 30 and 25%, respectively. By the endline, Group 1 revealed the highest engagement with a 55% participation rate, clear evidence to the project's impact in enhancing community involvement. Groups 2 and 3 achieved participation rates of 40 and 30%, respectively, while Group 4 showed an increase to 28% (Figure 3).

There is clear evidence that SHG households with intervention in the treatment GPs were more likely to participate in several trainings as should be the case, since the trainings were part of the intervention. During the endline survey, these households show relatively higher

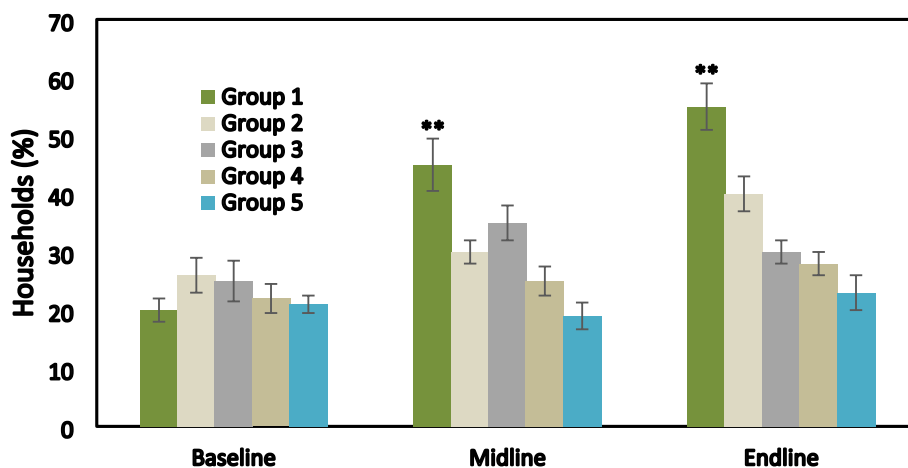


FIGURE 3

Participation in various trainings across the treatment and control groups. \*Indicate that data in the group is significantly higher over other groups during that survey at the level  $p = 0.05$ .

participation in trainings related to rice and wheat production, seed production technology, and other trainings for health, nutrition, kitchen gardens and composting (Figure 4). There is no evidence of spillovers in the trainings to non-SHG households (Figure 3). Therefore, the participation rates of non-SHG households in treatment GPs were like those in the control GPs. Similarly, there is no strong evidence that training participation was any higher for SHG households located in treatment GPs but not being selected for intervention.

The impact of the trainings on implementation practices was apparent. During the endline, survey, Group 1 exhibited the most significant improvement in the adoption of advanced seed production techniques. Approximately 70% of households in Group 1 reported the adoption of at least one new practice, such as seed treatment, proper drying, and improved storage methods. This reflects a high level of practical application of the trainings received. Group 3 followed with a 45% adoption rate, while Groups 2 and 4 had adoption rates of 40 and 35%, respectively. Besides, no significant difference was observed between Groups 2, 3, 4, and 5, indicating no spillover impact from Group 1 (Table 1). The adoption of practices was often correlated with the extent of trainings received and the initial engagement level. The detailed application of these practices, such as the use of improved seed storage facilities and adherence to recommended seed treatment protocols, was more pronounced in groups with higher training engagements.

### 3.2 Adoption of new varieties

A key component of the project was to introduce and improve the adoption of new climate resilient crop varieties through SHGs. Varietal adoption showed a progressive improvement across all groups, with significant differences observed between groups with varying levels of trainings and support. At the baseline, only 15% of households in Group 1 had adopted improved crop varieties of rice and/or wheat. This rate improved to 35% by midline and further to

50% by endline (Figure 5). This demonstrates a substantial increase in the adoption of drought tolerant rice variety Sahbhagi Dhan (SD) by Group 1 during the endline survey (Table 2). The potential benefits of this new variety are its drought tolerance in addition to being shorter duration. The shorter duration potentially affects the sowing date of the succeeding wheat crop which can translate into significantly higher yields. Group 3 also experienced a notable increase in adoption rates, from 12% at baseline to 40% at endline, indicating indirect effect from SHGs with intervention. In contrast, Groups 2 and 4 exhibited slower adoption rates, with final rates of 25 and 20%, respectively. The differences in adoption rates indicate the influence of trainings with inclination and ability of households to switch towards improved crop varieties.

### 3.3 Seed production, saving and distribution

The quantity of seed production (rice and wheat) saw marked improvements over the study period, particularly in Groups 1 and 3. At baseline, Group 1 produced 0.8 tons of seeds. This increased to 2.5 tons by endline, reflecting 212% growth in seed production. The seed production of Group 3 enhanced from 0.7 to 2.2 tons, representing an increase of 214%. Groups 2, 4, and 5 showed more modest increase in seed production, with final averages of 1.8, 1.6, and 1.6 tons, respectively (Figure 6). The differences in production levels correlate with the adoption rates and the level of trainings received. SHGs in treatment groups with extensive trainings on seed entrepreneurship development and improved varietal adoption, reported higher seed production volumes.

Seed saving (rice and/or wheat) practices revealed significant improvement, particularly in Group 1. By endline, 85% of households in Group 1 were actively saving seeds, compared to 40% at baseline. This increase in seed saving practices was concomitant with higher knowledge and implementation of improved seed production techniques. At the endline, 35 and 45% of the households stated seed saving in Groups 2 and 3, respectively (Figure 7). The amount of saved

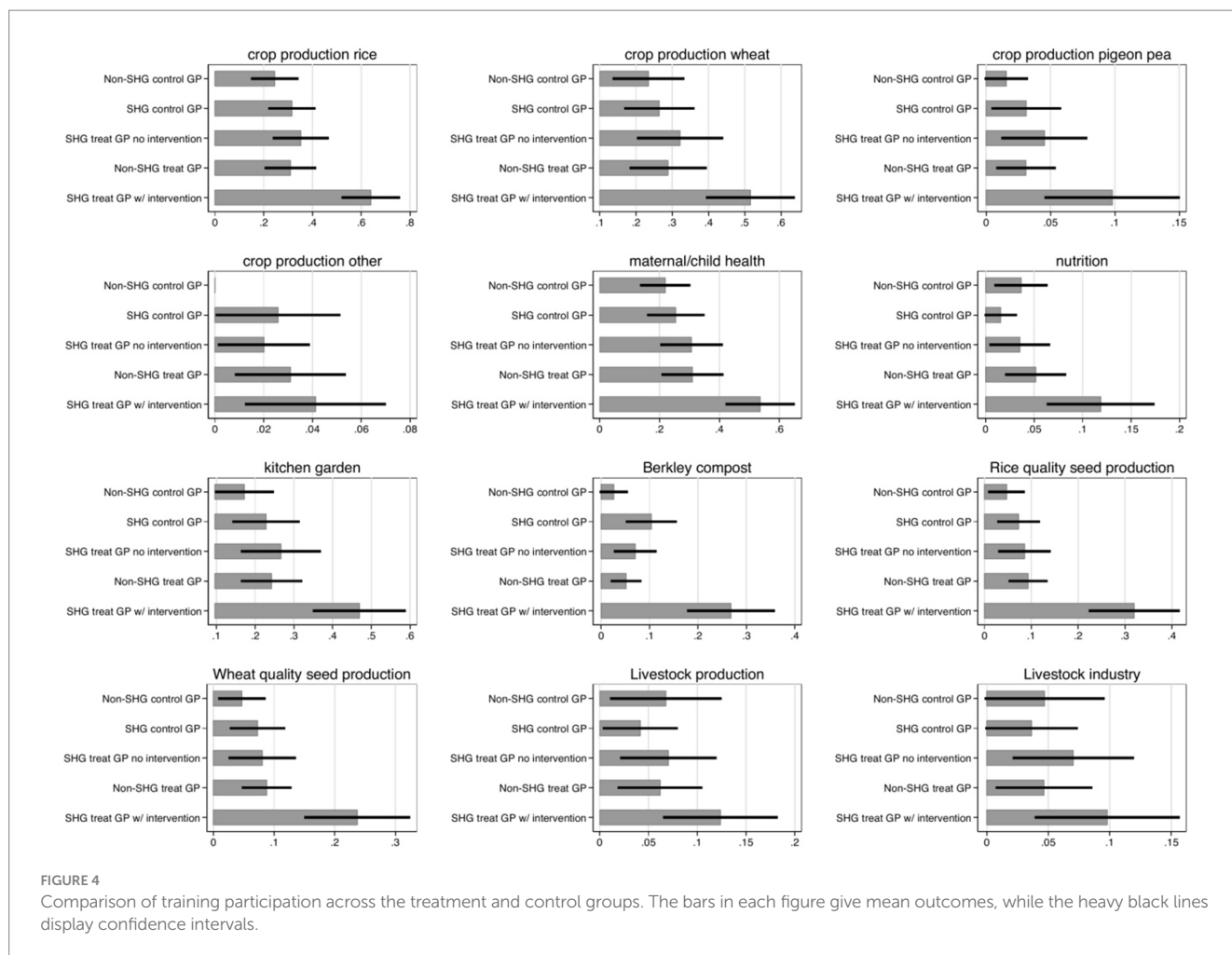


FIGURE 4 Comparison of training participation across the treatment and control groups. The bars in each figure give mean outcomes, while the heavy black lines display confidence intervals.

TABLE 1 Adoption of new agricultural practices by the treatment and control groups.

Treatment group	Adoption rate (%)	p-value (at 5% SL)	If difference is significant
1	70.5	0.0000	Significant
4	35.0		
3	45.0	0.0550	Non-significant
4	35.0		
2	40.0	0.2800	Non-significant
5	32.8		

seeds also increased with Group 1 households, saving an average of 20 kg per household by endline, up from 10 kg at baseline. Groups 2 and 3 saved 10 kg and 12 kg on average, respectively. The increase in seed saving reflects improved confidence in seed quality, and availability of high-quality seeds.

The endline data reveal that considerably higher percentage of farmers in Group 1 sourced rice and wheat seeds through SHG-led seed enterprises (Tables 3, 4). Group 3 households also reinforced the impact of community-led seed enterprises by their increased reliance on these seed business groups. These ventures are clearly alternatives to agricultural input and seed dealers or general shops, bringing in the

advantage of low cost and assured supply of the seeds of climate resilient varieties. The spillover effect of the intervention for non-SHG households on varietal and seed adoption was also observed. Non-SHG households were significantly more likely to use Sahbhagi Dhan and other improved varieties in treatment GPs compared to control GPs. Both situations led to the replacement of the traditional and low yielding crop varieties.

### 3.4 Production outcomes and profitability

Crop yield data revealed substantial enhancements, especially in Group 1. At baseline, rice yields in Group 1 averaged 3.2 tons per hectare. By endline, this had increased to 4.1 tons per hectare, representing a 28% increase (Figure 8). Wheat yields in Group 1 increased from 2.8 tons per hectare to 3.5 tons per hectare, a 25% increase (Figure 9). Group 3 also exhibited considerable yield enhancements, with rice yields rising from 3.0 to 3.8 tons per hectare, and wheat yields from 2.6 tons to 3.3 tons per hectare. Groups 2 and 4 had smaller improvements in crop yields, with final rice yields of 3.0 and 2.9 tons per hectare, and wheat yields of 2.7 and 2.6 tons per hectare, respectively. These results highlight the effectiveness of improved crop varieties and trainings in enhancing agricultural productivity and profitability.

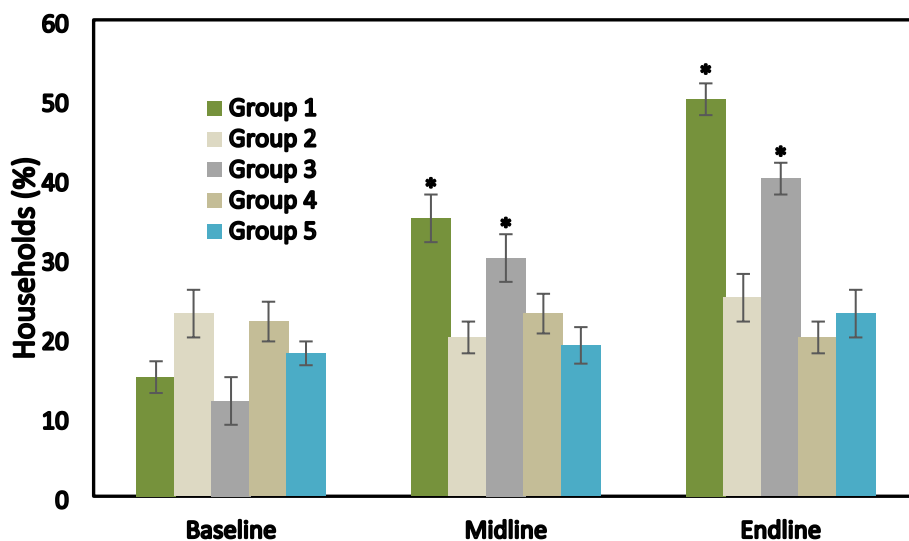


FIGURE 5 Adoption of new crop varieties by the treatment and control groups. \*Indicate that data in the group is significantly higher over other groups during that survey at the level  $p = 0.05$ .

TABLE 2 Adoption rate of Sahbhagi Dhan across the experimental groups.

Treatment group	Households adopting SD (%)	p-value (at 5% SL)	If difference is significant
1	43.8	0.0010	Significant
4	11.1		
3	31.8	0.0051	Significant
4	11.1		
2	12.7	0.7520	Non-significant
5	11.6		

### 3.5 Knowledge and awareness

Awareness of improved varieties was significantly higher by the endline. Group 1 had the highest level of awareness, with 85% of households knowing about Sahbhagi Dhan and other improved varieties (Table 5). Group 3 followed with 70%, while Groups 2, 4 and 5 had lower awareness levels of 55, 50 and 40%, respectively. The increased awareness was a direct outcome of the project interventions. Knowledge of seed production practices improved notably across all groups. Group 1 reported a significant increase in understanding advanced techniques, with 75% of households demonstrating familiarity of seed cleaning, treatment, and proper storage methods by endline. Groups 2 and 3 also showed improvements, with 55 and 60% of households, respectively, reporting increased familiarity. Group 4 and 5 had the lowest increase in familiarity, with only 50 and 42% of households showing improved understanding, respectively (Table 6). Spillover effects has been observed within and across the groups for awareness regarding improved varieties and seed production practices.

### 3.6 Impact on decision making

The endline data indicates that in some of the activities or aspects, women in Group 1 have shown higher decision-making capabilities than other groups. These activities include crop selection, variety selection, crop management and use of farm produce. This implies increased decision making in agriculture by household women due to the project interventions (Figure 10).

## 4 Discussion

The experimental results reveal the positive impact of the project interventions on seed production and distribution, adoption of new crop varieties, and overall agricultural productivity. The findings also suggest that in addition to the direct impacts on agricultural practices and outcomes, there were far-reaching socio-economic and gender-based effects. The continuous improvements observed in training participation, seed production, improved seed adoption, crop yields, and women’s empowerment provide a basis for recognizing how such community-based programs can lead to agricultural transformation in rural societies.

### 4.1 Training programs and their outreach

Trainings have long been acknowledged as a critical factor in the adoption of new agricultural technologies and practices. The persuasive enhancement in participation from baseline to endline, particularly in Group 1 (rising from 20 to 55%), illustrates the importance of outreach and engagement efforts. Previous studies have documented that early low participation in such programs often reflect initial reluctance in adoption for new practices and lack of awareness about their impending benefits (Rogers, 2003). However, as demonstrated in this

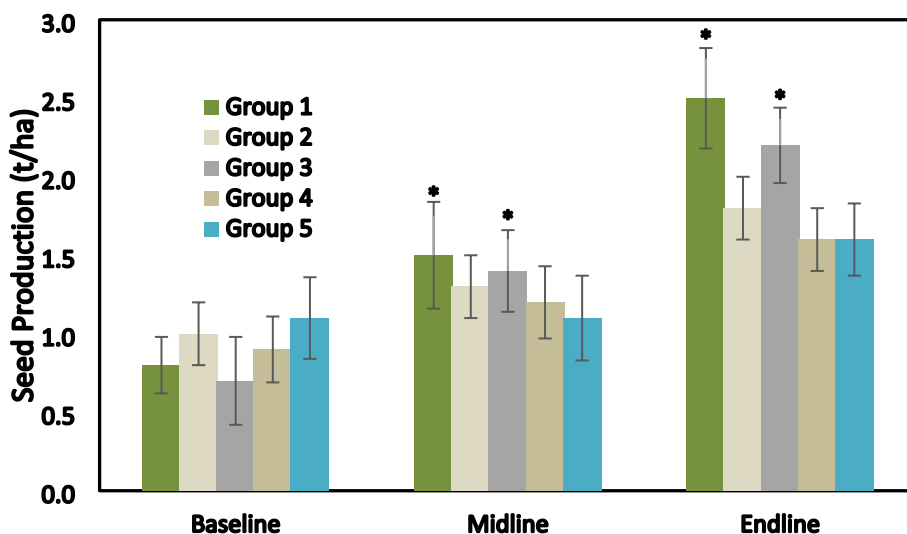


FIGURE 6 Seed production by various treatment and control groups. \*Indicate that data in the group is significantly higher over other groups during that survey at the level  $p = 0.05$ .

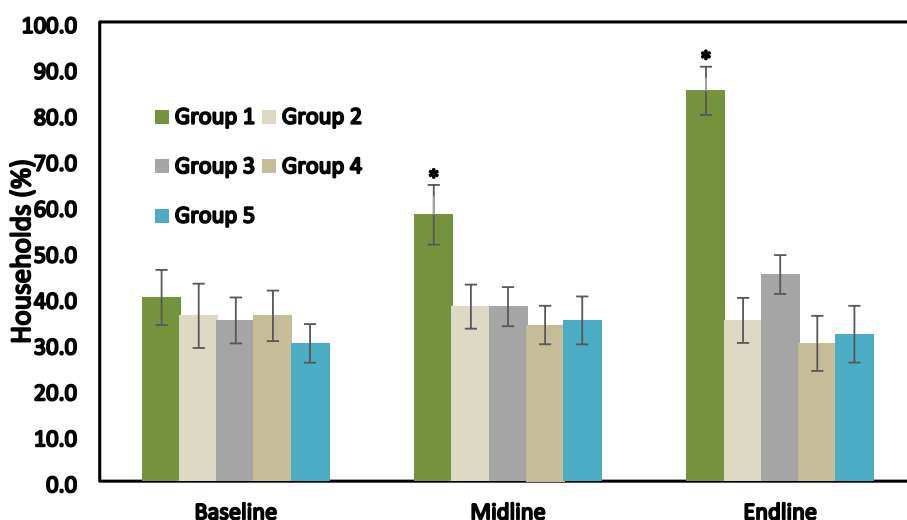


FIGURE 7 Seed saving by various treatment and control groups. \*Indicate that data in the group is significantly higher over other groups during that survey at the level  $p = 0.05$ .

TABLE 3 SHG-led seed enterprise as source of rice seed across the experimental groups.

Treatment group	Households (%) obtaining the seeds from SHG-led enterprise	$p$ -value (at 5% SL)	If difference is significant
1	49.1	0.0030	Significant
4	22.3		
3	36.2	0.0410	Significant
4	22.3		
2	15.7	0.0135	Significant
5	11.4		

TABLE 4 SHG-led seed enterprise as source of wheat seed across the experimental groups.

Treatment group	Households (%) obtaining the seeds from SHG-led enterprise	$p$ -value (at 5% SL)	If difference is significant
1	37.3	0.0000	Significant
4	21.5		
3	30.9	0.0000	Significant
4	21.5		
2	10.1	0.0153	Significant
5	5.0		

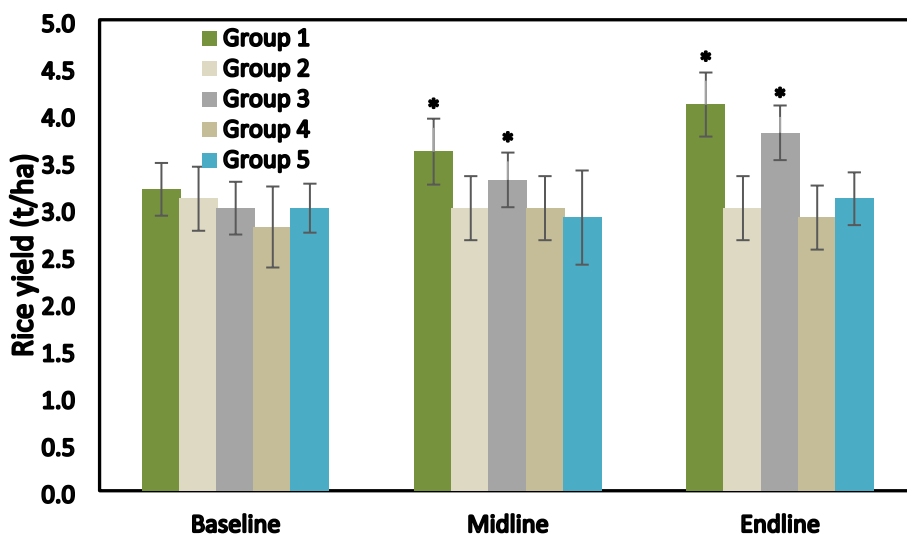


FIGURE 8 Comparison of household-level rice yields across the treatment and control groups. \*Indicate that data in the group is significantly higher over other groups during that survey at the level  $p = 0.05$ .

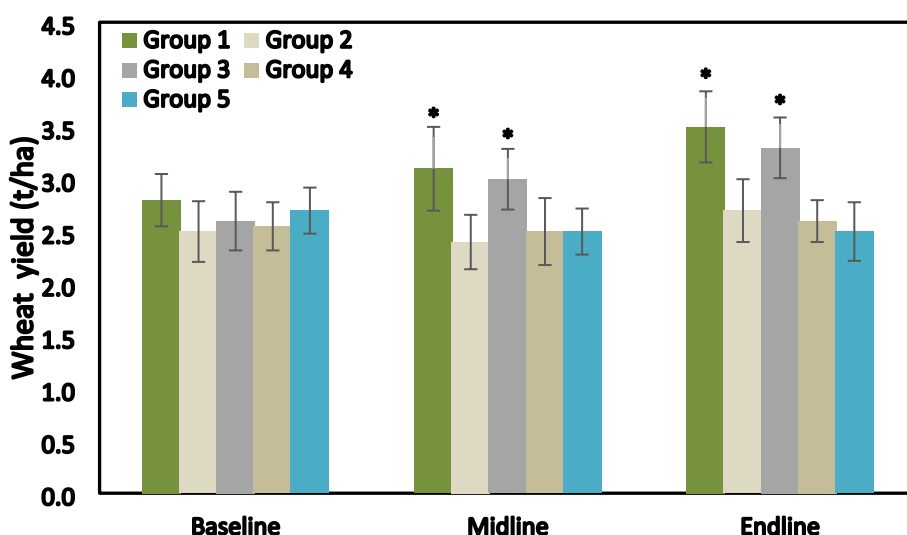


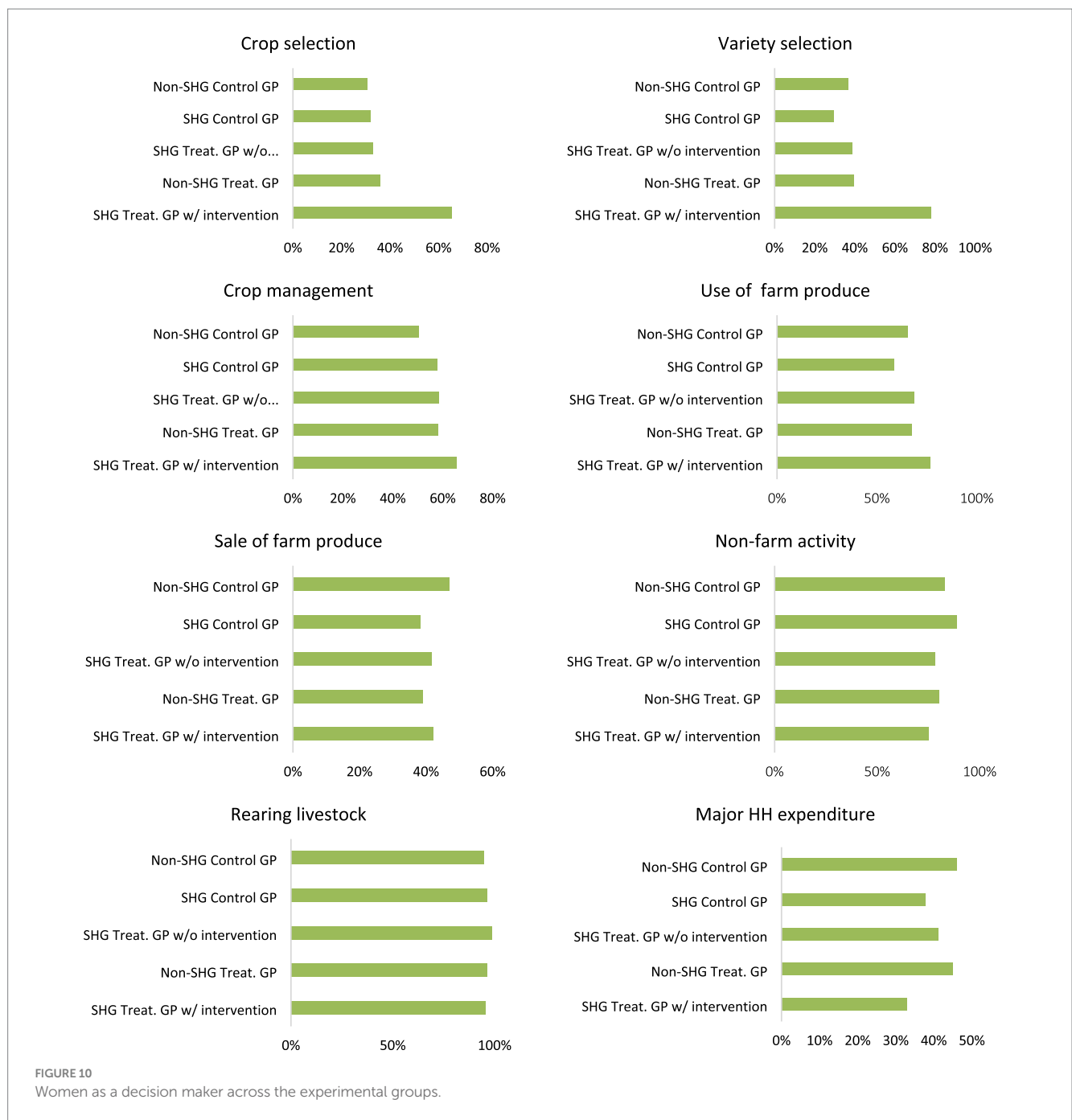
FIGURE 9 Comparison of household-level wheat yields across the treatment and control groups. \*Indicate that data in the group is significantly higher over other groups during that survey at the level  $p = 0.05$ .

TABLE 5 Awareness of improved varieties in rice across the experimental groups.

Treatment group	Households (%) with awareness of improved varieties	$p$ -value (at 5% SL)	If difference is significant
1	85.0	0.0000	Significant
4	50.3		
3	70.1	0.0410	Significant
4	50.3		
2	55.3	0.0076	Significant
5	40.0		

TABLE 6 Awareness of improved seed production practices across the experimental groups.

Treatment group	Households (%) with awareness of improved practices	$p$ -value (at 5% SL)	If difference is significant
1	75.0	0.0000	Significant
4	50.1		
3	60.1	0.0085	Significant
4	50.1		
2	55.4	0.0096	Significant
5	42.0		



study, when societies are exposed to the noticeable benefits of the trainings, participation levels can rise significantly (Davis et al., 2020). The success of Group 1 in both training participation and practice adoption, as opposed to the relatively lower engagement in Groups 2 and 4, suggests that a combination of effective communication strategies and palpable results (such as improved yields and quality of produce) can play a crucial role in supporting community engagements over time. Moreover, the lack of spillover effects in the participation of trainings across SHG and non-SHG households advocates that the impact of such activities remains constrained within the groups directly targeted by the interventions. This indicates the inadequacy in the diffusion of agricultural knowledge to non-SHG members, which has also been noted in other agricultural training programs as well (Dar et

al., 2017; De Janvry et al., 2017). In order to intensify the benefits, future interventions may need to concentration on mechanisms that facilitate information sharing beyond the targeted groups, such as farmer-to-farmer extension services and informal networks, as suggested by Anderson and Feder (2004).

## 4.2 Improved crop varieties and agricultural productivity

One of the key intentions of the project was to improve the adoption and dissemination of improved crop varieties, which are well-suited to the local agro-climatic conditions. The adoption of

Sahbhagi Dhan and other climate resilient varieties saw a significant increase, particularly in Group 1, where adoption rates increased from 15% at baseline to 50% by endline. The higher adoption rates in this group can be credited to the comprehensive trainings on seed production and performance of the new crop varieties. This aligns with findings by Tripp (2001), who emphasizes that the availability of seed of improved crop varieties alone is inadequate for guaranteeing adoption; rather, a well-functioning seed system along with farmers' awareness on the agronomic advantages of these varieties is indispensable. The notable increase in yields for rice (28%) and wheat (25%) among Group 1 households offers further confirmation that the adoption of improved varieties, coupled with appropriate training and extension services, can lead to substantial productivity gains. This has been validated by evidence from similar interventions in other parts of India, where the introduction of high-yielding, stress-tolerant varieties has been shown to enhance food security and reduce vulnerability to climate change (Mittal and Kumar, 2019; Sarkar and Singh, 2020).

Interestingly, spillover impacts were observed in varietal adoption among non-participating households in the treatment GPs, with a 25% increase in adoption by non-SHG members. This indicates that the introduction of resilient crop varieties through SHGs may have wider systemic impacts beyond the immediate program beneficiaries through seed sales by SHGs or exchange. The participation of SHGs in seed production and dissemination generated a reliable and low-cost alternative to private seed dealers, thus expanding access to seeds of improved varieties for the wider farming community. However, making improved crop varieties available does not promise widespread adoption. Factors such as inadequate training, restricted access to inputs (especially seeds), and established preferences for traditional varieties may impede the transition to new technologies. Future programs could benefit from a more refined understanding of local barriers to adoption, including financial checks and risk antipathy, as highlighted in the work of Foster and Rosenzweig (2010). Modifying interventions to address these challenges, such as providing credit facilities for inputs or offering more personalized advisory services, could help in bridging the adoption gap across various groups (Nair and Kumar, 2021; Wang and Zhang, 2022).

### 4.3 Seed production and distribution

The substantial escalation in seed production in Groups 1 (212%) and 3 (214%) reflects the effectiveness of the project in increasing seed entrepreneurship and varietal adoption. The progress in seed saving practices, particularly in Group 1, with an increase from 10 kg to 20 kg per household, indicates improved confidence in seed quality and adoption of better seed management practices (Wang and Zhang, 2022). The inclination towards SHG-led seed enterprises in Groups 1 and 3 over traditional input sources highlights their role in providing reliable access to seeds of climate-resilient crop varieties. Our study advocates that effective training and community-led seed enterprises can considerably improve seed production and dissemination. However, the variability in outcomes indicates the need for customized support to attain widespread impact (Dar et al., 2021).

## 4.4 Economic and social outcomes

The observed enhancements in crop productivity are indicative of substantial gains in profitability due to the interventions. Group 1, which received extensive trainings and access to improved varieties, showed notable increase in rice and wheat yields. This increase in yields not only improves agricultural productivity but also translates to higher profitability for farmers, as greater yields lead to high marketable surplus and potential income (Smith et al., 2020; Kumar P. et al., 2021). The findings are supported by previous studies that signifies the importance of improved varieties and targeted trainings in increasing crop productivity and economic returns (Jones et al., 2018; Patel et al., 2019).

The substantial improvements in crop yields and seed production have resulted in increased profitability, which directly benefited women by augmenting their economic contributions and decision-making power within their households and communities (Beuchelt and Badstue, 2013). Women's involvement in seed production and management not only improves household income but also can uplift their status and influence in agrarian practices. The empowerment resulted in greater participation in community-level farming enterprises, indicating the crucial role of gender-focused interventions in supporting social equity and economic development in rural societies (Chowdhury et al., 2017; Doss, 2018).

## 4.5 Sustainability and future directions

The project interventions have revealed that community-based seed systems fastened in SHGs can be effective in enhancing agricultural productivity, ensuring food and seed security, besides empowering women. However, the sustainability of these impacts will depend on several factors. One key consideration is the long-term viability of the SHG-led seed production and dissemination model. As noted by Sperling and Cooper (2004), community seed systems often face challenges related to seed quality assurance, market access, and scalability. Ensuring that SHGs continue to receive technical backing and access to early generation seeds will be crucial for sustaining the gains realized through the interventions.

Additionally, while the project has made substantial progress in improving agricultural outcomes, further attention is required to address the economic barriers to profitability. The incorporation of complementary interventions, such as access to finance, improved market linkages, and labor-saving technologies, could help augment the economic resilience of smallholder farmers and ensure that they can fully benefit from yield enhancements. Policymakers and development experts should also consider the potential for scaling up such programs to reach a larger number of farmers, while maintaining the focus on community empowerment and gender equality that has been central to the project success.

## 4.6 Theory of change for group-led seed enterprises

A Theory of Change (ToC) perspective helps generalize the study findings for other SHGs, FPOs and FPOCs seeking to operationalize seed production enterprises. The ToC suggests that targeted inputs

(capacity building, access to early generation seed and institutional support) enable women- or group-led collectives to function as decentralized extension and seed dissemination platforms. These activities lead to improved varietal adoption, local seed availability and reduced dependence on external dealers, ultimately resulting in higher productivity, enhanced farm incomes and strengthened local seed systems. This framework provides a replicable pathway for scaling community-based seed enterprises beyond the study area.

## 4.7 Policy recommendations

Based on the findings and limitations of this study, the following policy recommendations are proposed:

- Institutionalize women-led SHGs as a complementary extension mechanism by formally integrating them into public agricultural extension and seed dissemination programs, particularly in regions with limited outreach of conventional extension services.
- Promote decentralized, community-based seed production systems through targeted technical support and access to early generation seeds, enabling SHGs to supply affordable, quality seeds of climate-resilient varieties such as drought-tolerant rice.
- Strengthen capacity-building investments by expanding the frequency, duration, and thematic coverage of trainings for SHG members, with a focus on seed quality assurance, business management and climate-resilient agronomic practices.
- Enhance convergence between development programs and seed systems institutions to improve market linkages, certification support and financial access for SHG-led seed enterprises, addressing sustainability and scalability constraints identified in the study.
- Support rigorous monitoring and evaluation frameworks in future programs to capture long-term impacts, spillover effects and gender-differentiated outcomes, addressing current limitations related to sample attrition and reliance on group-level comparisons.

## 5 Conclusion

The interventions have demonstrated a substantial progress in strengthening the informal seed sector and promoting agricultural development. The key strategy of mobilizing Self-Help Groups (SHGs) to facilitate access to quality seeds has proven effective across multiple dimensions. Throughout the baseline, midline, and endline assessments, the intervention has consistently improved seed availability, increased agricultural productivity, and empowered women farmers by enhancing their decision-making roles within both household and farming activities. Notably, the spillover effects extended beyond the immediate beneficiaries, positively influencing surrounding communities by fostering a knowledge-sharing culture and improving access to agricultural inputs particularly through informal networks. These results underscore the transformative potential of SHG-driven

seed production and distribution models in empowering women and advancing sustainable agricultural practices. The impact of the project interventions suggest promising prospects for long-term growth, sustainability, and scalability of this approach, both within Uttar Pradesh and in similar contexts elsewhere.

## Data availability statement

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

## Author contributions

MD: Conceptualization, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing, Funding acquisition, Project administration, Resources, Supervision, Visualization. SW: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. AM: Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – review & editing. PT: Data curation, Investigation, Project administration, Supervision, Writing – review & editing. NZ: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing. SN: Investigation, Methodology, Supervision, Writing – review & editing. MH: Investigation, Methodology, Supervision, Writing – review & editing. SK: Project administration, Resources, Supervision, Writing – review & editing.

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## Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fsufs.2026.1725530/full#supplementary-material>

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