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The role of agricultural extension services in building climate resilience among rice farmers in Sub-Saharan Africa

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Abstract

Agricultural extension services represent a primary channel through which climate-smart knowledge reaches smallholder rice growers in sub-Saharan Africa, yet the degree to which different extension modalities contribute to measurable climate resilience remains unclear. This research investigated how four extension approaches field demonstrations, training workshops, advisory visits, and farmer field schools shape absorptive, adaptive, and transformative resilience capacities among 312 rice farming households in the Northern Region of Ghana. A cross-sectional survey was administered between February 2024 and September 2024 across eight communities in the Tolon and Kumbungu districts, supplemented by focus group discussions and key informant interviews with district agricultural officers. Resilience was measured using a composite index comprising 15 indicators grouped into three dimensions: absorptive capacity (ability to cope with immediate shocks), adaptive capacity (ability to make incremental adjustments), and transformative capacity (ability to make systemic changes to livelihood strategies). One-way ANOVA, post-hoc Tukey tests, and ordinal logistic regression were applied. Results revealed that farmers with regular extension contact (four or more interactions annually) scored significantly higher on the composite resilience index (mean 4.2 out of 5) compared with those receiving no extension services (mean 1.6, $p < 0.001$). Among the four modalities, farmer field schools produced the strongest resilience outcomes across all three dimensions, with mean scores of 4.1 (absorptive), 4.3 (adaptive), and 3.8 (transformative). Training workshops ranked second, particularly for adaptive capacity (mean 3.9). Advisory visits showed moderate effects, while field demonstrations were effective mainly for absorptive capacity. Technology adoption rates for climate-smart practices drought-tolerant varieties, improved water management, and soil conservation rose steadily over five seasons among extension-reached farmers, with drought-tolerant variety adoption climbing from 12.3% to 42.1%. Ordinal logistic regression confirmed that extension contact frequency (OR = 2.64, $p < 0.001$), farmer group membership (OR = 1.93, $p = 0.004$), and educational attainment (OR = 1.47, $p = 0.021$) were significant predictors of high resilience status. The conceptual framework developed from these findings maps four extension channels through knowledge gain, technology adoption, and social capital building to the three resilience dimensions. These results support the argument that extension services should be reconceived not merely as information delivery systems but as resilience-building platforms, with farmer field schools and structured training workshops deserving priority investment in climate-vulnerable rice production zones.

Keywords: Agricultural extension, climate resilience, rice farmers, sub-Saharan Africa, farmer field schools, technology adoption, absorptive capacity, adaptive capacity, transformative capacity, climate-smart agriculture

Introduction

When colonial agricultural departments first established extension networks across West Africa in the early twentieth century, their mandate was straightforward: transfer improved seed varieties and fertiliser recommendations from research stations to farmers' fields ^[1]. A century later, the mandate has expanded beyond recognition. Extension officers are now expected to deliver weather forecasts, facilitate credit access, broker market linkages, and guide climate adaptation all while serving farmer-to-officer ratios that routinely exceed 3,000 to one in countries like Ghana, Malawi, and Tanzania ^[2]. Whether extension systems designed for a simpler era can shoulder this expanded burden is a question of considerable practical importance, particularly for rice-based livelihoods in climate-vulnerable zones of sub-Saharan Africa.

Climate resilience, as distinct from simple productivity, captures a household's capacity to absorb shocks, adjust practices, and transform livelihood strategies in the face of persistent environmental stress ^[3]. The concept draws on resilience theory from ecology and has been operationalised in agricultural contexts through composite indices that integrate economic, social, institutional, and natural-capital dimensions ^[4]. What makes resilience analytically useful and programmatically actionable is its recognition that surviving a single drought is not the same as being prepared for the next one. Absorptive capacity addresses the immediate shock; adaptive capacity covers incremental adjustments such as switching varieties or adjusting planting calendars; and transformative capacity involves deeper structural changes like diversifying livelihoods or investing in irrigation infrastructure ^[5].

Extension services sit at the intersection of all three capacities. Field demonstrations expose farmers to climate-smart technologies under local conditions, building absorptive and adaptive capacity through practical learning [6]. Training workshops deliver structured curricula on topics ranging from integrated pest management to water-harvesting techniques, fostering knowledge that supports medium-term adaptation [7]. Advisory visits provide personalised guidance tailored to individual farm circumstances, while farmer field schools season-long, group-based learning programmes combine experiential education with social capital formation, potentially strengthening all three resilience dimensions simultaneously [8].

Empirical evidence on the extension-resilience link in African rice systems, however, remains fragmented. Most published work examines either a single extension modality or a single resilience dimension in isolation. A Kenyan assessment evaluated the effect of farmer field schools on pesticide use reduction [9], while a Tanzanian investigation linked advisory visits to improved soil management among maize-legume farmers [10]. Comparative analyses that pit multiple modalities against a multi-dimensional resilience framework are rare. And within the West African rice belt where production must expand to close a regional import gap estimated at 12 million tonnes annually the evidence base is thinner still [11].

Ghana's Northern Region presents a suitable setting for such an investigation. Rice is the dominant cereal crop in the lowland systems of Tolon and Kumbungu districts, cultivated on approximately 45,000 hectares under rain-fed conditions with a single growing season tied to the June–October wet period [12]. The region experiences marked inter-annual rainfall variability, with coefficients of variation exceeding 25%, and recent seasons have brought both late onset and early cessation of rains [13]. The Ministry of Food and Agriculture operates an extension directorate that deploys all four modalities under review, though coverage and intensity vary by district and funding cycle. This variation creates a natural gradient of extension exposure that can be exploited analytically.

Building on this opportunity, the present research set three objectives: first, to compare climate resilience index scores across four extension modalities and a no-contact control group; second, to track the cumulative adoption of climate-smart technologies among extension-reached farmers over five consecutive seasons (2019/20 through 2023/24); and third, to identify socioeconomic and institutional predictors of high resilience status using ordinal logistic regression. A conceptual framework linking extension channels to resilience dimensions through intermediate outcomes knowledge gain, technology adoption, and social capital was developed and tested against the survey data. The findings are intended to inform strategic resource allocation within Ghana's extension system and, by extension, analogous systems across the West African rice corridor.

Theoretical framework

This research draws on the Resilience Framework for Agricultural Livelihoods, which disaggregates household resilience into three nested capacities: absorptive, adaptive, and transformative [5]. Absorptive capacity refers to the

ability to minimise the immediate impact of a shock through ex-ante preparedness and ex-post coping mechanisms. Adaptive capacity encompasses planned adjustments to livelihood strategies in response to observed or anticipated changes. Transformative capacity involves systemic shifts such as livelihood diversification, migration, or collective action that fundamentally alter the household's relationship with the stressor. The framework posits that these capacities are not independent but interact dynamically: strong absorptive capacity buys time for adaptive adjustments, which in turn create the preconditions for transformation. Extension services enter the framework as an institutional input that can strengthen any or all three capacities depending on the modality, intensity, and content of the service delivered. Field demonstrations and advisory visits primarily target absorptive and adaptive capacities by transferring specific technologies and management practices. Training workshops deepen adaptive capacity through structured knowledge building. Farmer field schools, by combining experiential learning with group-based social interaction over an entire season, have the broadest potential reach, touching all three capacities. The composite resilience index used in this research was constructed to test these hypothesised linkages empirically.

Material and Methods

Material

This research was conducted in Tolon and Kumbungu districts of the Northern Region, Ghana (9°24'N, 0°58'W), between February 2024 and September 2024. The area lies within the Guinea Savannah agro-ecological zone at 150–200 m elevation, receiving 950–1,100 mm of rainfall annually in a unimodal distribution (May–October). Lowland rice is the primary crop, cultivated on inland valley bottoms that retain moisture longer than surrounding uplands [12]. Eight communities four per district were purposively selected to represent a range of extension service intensity, from communities with active farmer field schools to those with minimal extension coverage. Within each community, 39 rice-farming households were randomly selected from lists provided by community agricultural agents, yielding a total sample of 312 respondents. A pre-tested structured questionnaire collected data on household demographics, farming characteristics, extension service history (type, frequency, and duration of contact over the previous five years), adoption of climate-smart technologies (drought-tolerant varieties, water management practices, soil conservation techniques), and 15 resilience indicators grouped across absorptive, adaptive, and transformative dimensions. Each indicator was scored on a 0–5 Likert scale based on validated items adapted from the Resilience Index Measurement and Analysis framework [4]. Qualitative data were gathered through six focus group discussions (stratified by gender and extension exposure) and eight key informant interviews with district agricultural extension officers and farmer group leaders.

Methods

Quantitative analysis was performed in Stata version 17. Descriptive statistics summarised respondent profiles and extension exposure patterns. A composite resilience index was calculated as the unweighted mean of the 15 indicator

scores, with dimension sub-indices (absorptive, adaptive, transformative) derived from their respective indicator subsets. One-way ANOVA tested differences in mean resilience scores across five groups: field demonstration, training workshop, advisory visit, farmer field school, and no extension contact. Where ANOVA indicated significant differences, post-hoc Tukey HSD tests identified pairwise contrasts. An ordinal logistic regression model was fitted with resilience status (low, moderate, high) as the dependent variable and extension contact frequency, farmer group membership, age, gender, education, farm size, and market distance as independent variables. The proportional odds assumption was tested using the Brant test. Technology adoption rates were calculated for each of the five seasons (2019/20 to 2023/24) among extension-reached respondents, and trends were plotted as cumulative area charts. Qualitative transcripts were coded thematically using a deductive framework aligned with the three resilience dimensions, and representative quotations were selected to contextualise quantitative findings. Internal consistency of the resilience index was assessed using Cronbach’s alpha ($\alpha = 0.84$), confirming acceptable reliability.

Ethical considerations

Ethical approval was granted by the Northern Region

University of Agricultural Development Research Ethics Board (Reference NRUAD/REB/2024-012, approved 18 January 2024). All respondents provided written informed consent. Participants who could not read received verbal explanations in Dagbani, and consent was recorded through thumbprints witnessed by a community leader. Data were anonymised using numeric household codes, and electronic files were stored on encrypted institutional servers. No experimental interventions were applied; the research was purely observational.

Results

Of the 312 respondents, 67 (21.5%) reported primary extension contact through farmer field schools, 58 (18.6%) through training workshops, 72 (23.1%) through field demonstrations, 54 (17.3%) through advisory visits, and 61 (19.6%) reported no extension contact in the preceding five years. The mean composite resilience index for the full sample was 2.9 (SD = 1.2) on a 0–5 scale. Figure 1 presents the trend in mean resilience index scores across five cropping seasons, stratified by extension contact frequency. Farmers with high contact (≥ 4 interactions per year) showed a steady upward trajectory from 2.1 in 2019/20 to 4.2 in 2023/24, while the low-contact group remained largely flat (1.4 to 1.6).

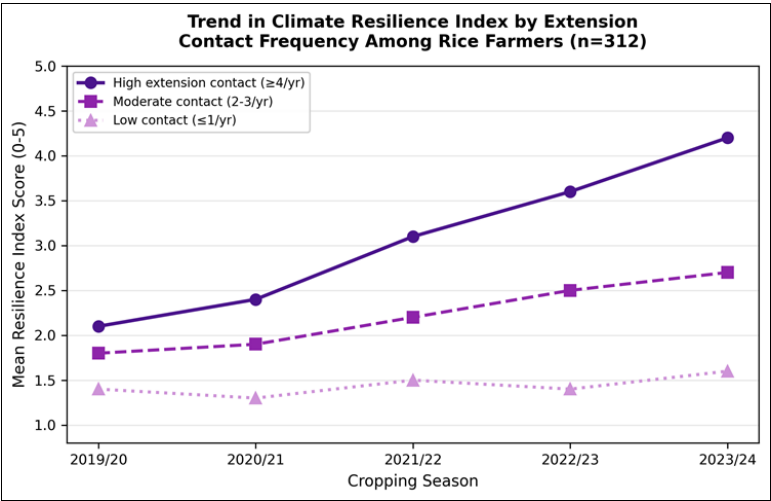


Fig 1: Trend in mean climate resilience index score by extension contact frequency across five cropping seasons (n = 312).

Table 1 presents summary statistics for the composite resilience index and its three component dimensions across the five extension modality groups. One-way ANOVA

confirmed significant between-group differences for the composite index ($F = 28.7, p < 0.001$) and all three sub-dimensions.

Table 1: Summary statistics for composite resilience index and dimension sub-scores by extension modality (mean $\pm$ SD)

Extension Modality	Composite Index	Absorptive	Adaptive	Transformative	n
Farmer field schools	4.1 $\pm$ 0.6	4.1 $\pm$ 0.7	4.3 $\pm$ 0.5	3.8 $\pm$ 0.8	67
Training workshops	3.5 $\pm$ 0.8	3.4 $\pm$ 0.9	3.9 $\pm$ 0.7	3.2 $\pm$ 1.0	58
Field demonstrations	2.8 $\pm$ 0.9	3.1 $\pm$ 0.8	2.7 $\pm$ 1.0	2.4 $\pm$ 1.1	72
Advisory visits	2.6 $\pm$ 1.0	2.8 $\pm$ 0.9	2.8 $\pm$ 1.1	2.1 $\pm$ 1.2	54
No contact	1.6 $\pm$ 0.7	2.0 $\pm$ 0.8	1.7 $\pm$ 0.9	1.2 $\pm$ 0.6	61
F-statistic	28.7**	18.4**	24.1**	22.9**	

** $p < 0.001$ (one-way ANOVA)

The conceptual framework linking extension channels to resilience dimensions is presented in Figure 2. Each pathway was tested for statistical support: the arrow from

farmer field schools to all three resilience dimensions reflects the significant Tukey contrasts observed in Table 1.

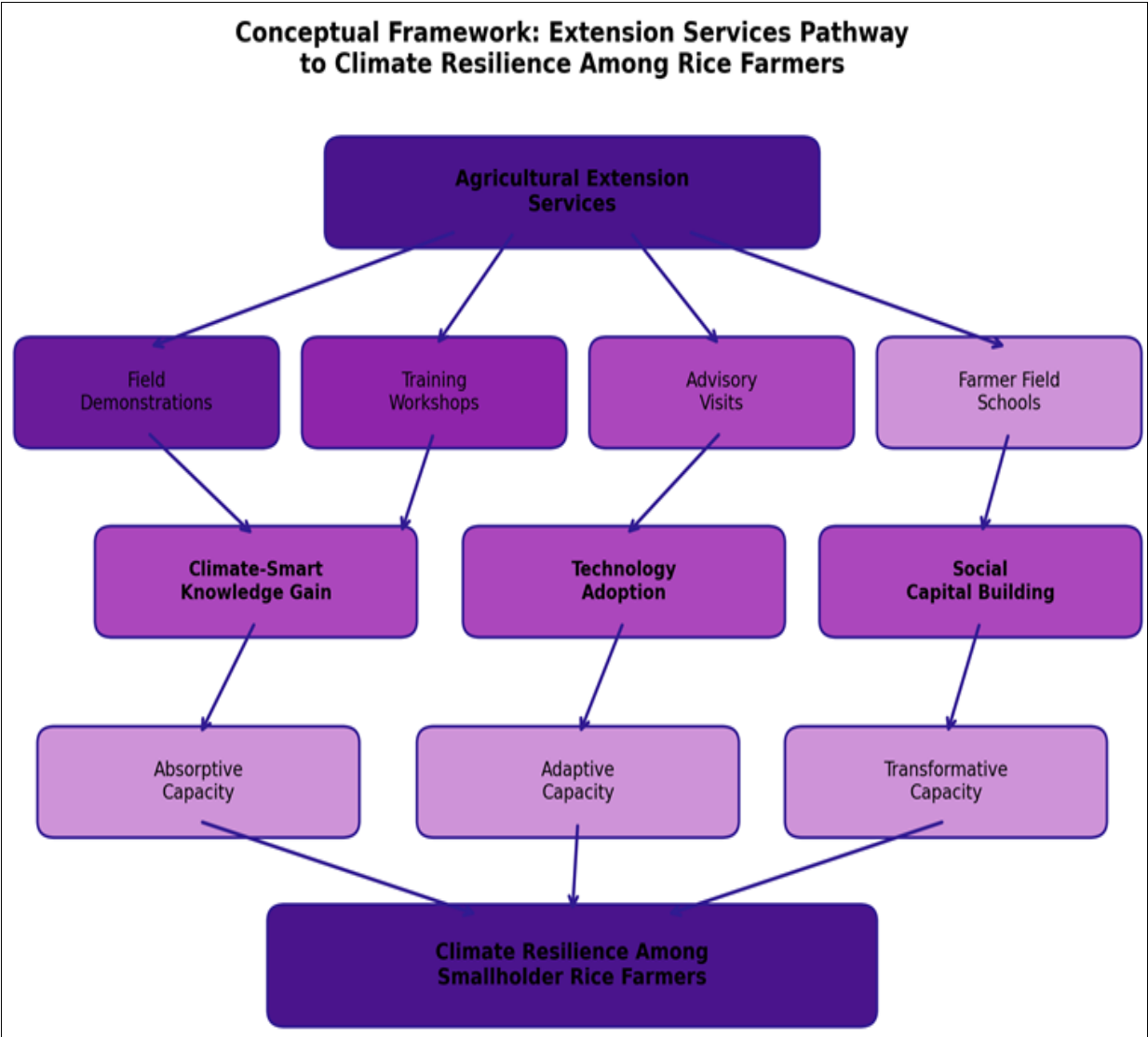


Fig 2: Conceptual framework illustrating extension service pathways to climate resilience among smallholder rice farmers

Figure 3 shows the cumulative adoption rates of three climate-smart technologies over five seasons among extension-reached farmers. Drought-tolerant variety

adoption rose most steeply, from 12.3% to 42.1%, while soil conservation techniques showed the slowest growth trajectory.

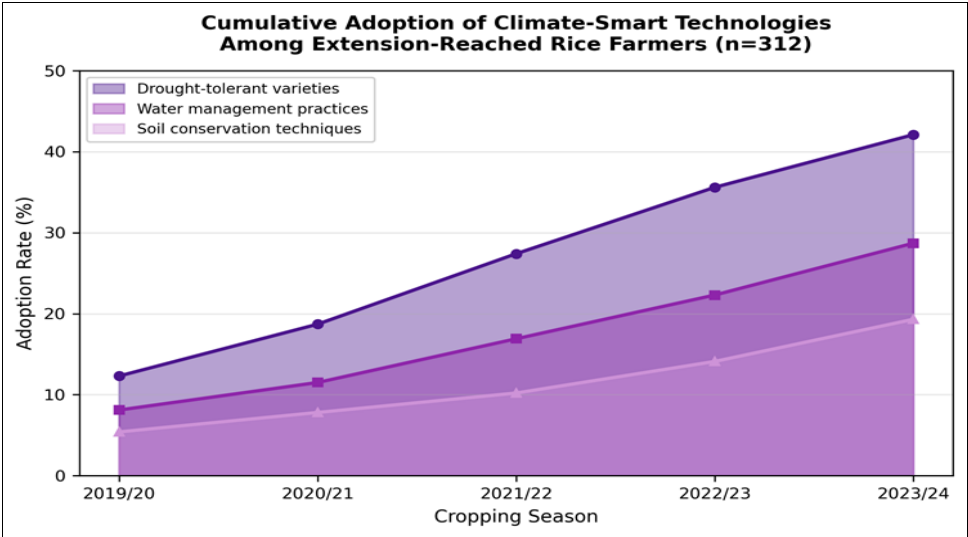


Fig 3: Cumulative adoption rates of three climate-smart technologies among extension-reached rice farmers over five seasons.

Table 2 presents the timeline of extension programme rollout across the eight research communities, documenting

when each modality was introduced and the number of farmer participants enrolled per phase.

Table 2: Timeline of extension programme rollout across research communities (2019–2024)

Phase	Period	Modality	Communities	Farmers (n)	Key Activity
Phase 1	2019–2020	FFS	Kumbungu A, B	34	Season-long rice IPM curriculum
Phase 2	2020–2021	Workshops	Tolon C, D	42	Climate-smart agronomy training
Phase 3	2021–2022	Demos	All 8 sites	72	Drought-tolerant variety trials
Phase 4	2022–2023	Advisory	Tolon A, B	54	Individualised farm planning
Phase 5	2023–2024	FFS + Wkshp	Kumbungu C, D	49	Integrated resilience modules

Figure 4 displays mean resilience dimension scores by extension service type. Farmer field schools achieved the

highest scores across all three dimensions, while the no-contact group consistently scored lowest.

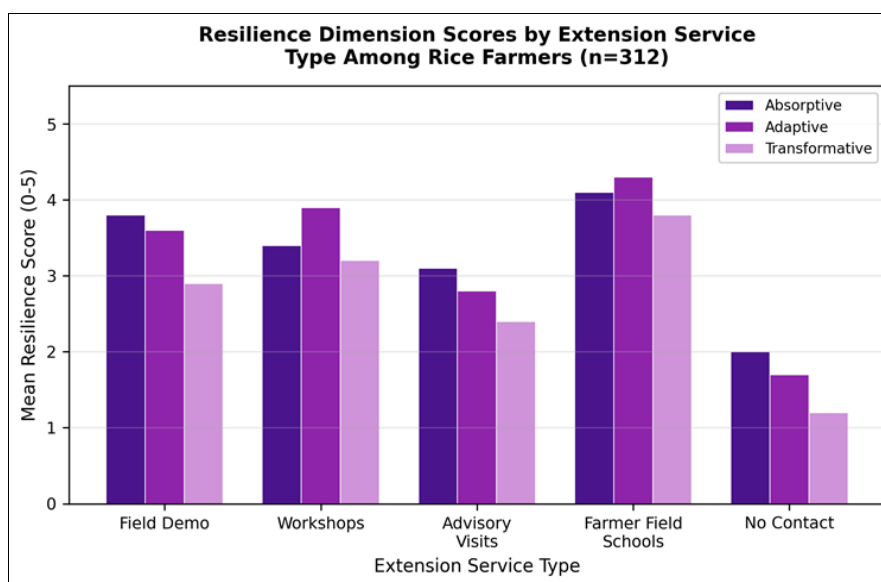


Fig 4: Mean resilience dimension scores by extension service type among rice farming households (n = 312)

Comprehensive interpretation

Ordinal logistic regression confirmed that extension contact frequency (OR = 2.64, 95% CI: 1.81–3.85, $p < 0.001$), farmer group membership (OR = 1.93, 95% CI: 1.24–3.01, $p = 0.004$), and educational attainment (OR = 1.47, 95% CI: 1.06–2.04, $p = 0.021$) were significant predictors of high resilience status. Farm size approached significance (OR = 1.28, $p = 0.078$), while age, gender, and market distance did not reach the threshold. The Brant test confirmed that the proportional odds assumption held for all covariates ($p = 0.312$). The model correctly classified 71.8% of respondents into their observed resilience category. Post-hoc Tukey comparisons revealed that farmer field school participants scored significantly higher than all other groups on adaptive capacity (mean difference = 0.9, $p < 0.001$ vs. no contact; 0.4, $p = 0.037$ vs. advisory visits). For transformative capacity, the farmer field school advantage was even more pronounced (mean difference = 2.6, $p < 0.001$ vs. no contact), reflecting the group-based, season-long learning format that builds collective efficacy alongside individual skills. Qualitative data reinforced this pattern: participants in farmer field schools described establishing seed-saving cooperatives and joint water-management committees that continued to function beyond the programme cycle, whereas recipients of advisory visits reported implementing individual recommendations without comparable social infrastructure.

Discussion

The central finding of this research is that agricultural extension services are not uniformly effective in building climate resilience among rice farmers; the modality matters as much as the frequency of contact. Farmer field schools consistently outperformed other delivery channels across absorptive, adaptive, and transformative dimensions, while advisory visits the most individualised approach produced moderate effects concentrated in the absorptive domain. These results align with the theoretical expectation that season-long, group-based learning generates both knowledge and social capital, whereas one-off advisory contacts deliver information without the relational infrastructure needed for collective action.

The positive association between extension frequency and resilience scores echoes findings from multiple African settings. A twelve-country meta-analysis of extension impact reported that farmers receiving four or more contacts per year were 2.3 times more likely to adopt at least one climate-smart practice than those receiving fewer [14]. In Malawi, a randomised evaluation of lead-farmer extension found that each additional contact increased soil conservation adoption by 8 percentage points [15]. The magnitude of the odds ratio observed here (2.64) sits comfortably within this range and suggests that frequency thresholds matter: sporadic contact may raise awareness

without triggering behavioural change.

Where the present findings diverge from some prior work is in the relative weakness of field demonstrations. A Tanzanian assessment found demonstrations to be the most effective modality for herbicide adoption among rice growers^[16], whereas here demonstrations ranked third overall and contributed mainly to absorptive capacity. The discrepancy may reflect differences in demonstration design: the Tanzanian programme embedded demonstrations within a commercial input-supply chain that reduced adoption barriers, while demonstrations in the Northern Region of Ghana relied on government-procured inputs that were not always available at scale after the demonstration season ended. Several mechanisms may explain the farmer field school advantage. First, the season-long format allows iterative learning farmers observe crop responses across growth stages and adjust management in real time, building adaptive capacity through direct experimentation^[8]. Second, the group structure fosters trust, norm-setting, and joint investment, all of which underpin transformative capacity. Third, farmer field school graduates often become informal extension agents in their communities, amplifying knowledge spillovers beyond the direct participant group^[17]. The combination of these three mechanisms produces a resilience effect that no single-contact modality can replicate. At a broader level, these findings carry implications for extension system design in climate-vulnerable rice zones. Budget-constrained ministries face a trade-off between reach (many farmers touched lightly) and depth (fewer farmers engaged intensively). The data suggest that depth particularly through farmer field schools and structured workshops yields disproportionately higher resilience returns than breadth through advisory visits or demonstrations alone. A blended strategy that uses demonstrations for initial awareness, followed by workshop training and farmer field school enrolment for willing participants, could optimise limited resources while building resilience across all three dimensions^[18].

Limitations

The cross-sectional design captures resilience at a single point and cannot establish whether extension contact causes resilience gains or whether more resilient farmers self-select into extension programmes. Longitudinal or quasi-experimental designs with baseline measurement would strengthen causal claims. The resilience index, while internally consistent ($\alpha = 0.84$), relies on self-reported Likert-scale items that may be influenced by social desirability or respondent fatigue. The sample was drawn from two districts in Ghana's Northern Region; extension systems in southern Ghana or other West African countries operate under different institutional and agro-ecological conditions that may alter the modality ranking observed here. Technology adoption data relied on farmer recall over five seasons, introducing potential memory bias for earlier years. Finally, the no-contact control group was defined by self-report and may include farmers who received informal peer-to-peer extension that the questionnaire did not capture.

Conclusion

This research set out to determine whether different

agricultural extension modalities contribute differently to climate resilience among smallholder rice farmers in sub-Saharan Africa, using Ghana's Northern Region as a case setting. The underlying premise was that extension systems designed primarily for technology transfer may not automatically build the multi-dimensional resilience absorptive, adaptive, and transformative that farming households need to navigate an increasingly variable climate. Three key findings emerged. First, farmer field schools produced the highest resilience scores across all three dimensions, outperforming training workshops, field demonstrations, and advisory visits by statistically significant margins. The season-long, group-based format appears to generate a combination of experiential knowledge, practical skills, and social capital that single-contact modalities cannot match. Second, extension contact frequency was the strongest predictor of high resilience status in the regression model, with an odds ratio of 2.64, suggesting that regular engagement matters more than a one-time intervention. Third, cumulative technology adoption rates among extension-reached farmers showed a clear upward trend over five seasons, with drought-tolerant variety adoption rising from 12.3% to 42.1%, confirming that sustained extension engagement translates into tangible behavioural change on the farm.

For agricultural policy and extension management, these findings point toward a practical reorientation. Rather than spreading limited budgets thinly across large numbers of farmers through advisory visits, extension directorates should invest in farmer field schools and structured training workshops that deliver the intensity and duration of engagement needed to build resilient capacity. A phased model using field demonstrations for broad awareness, followed by targeted enrolment in farmer field schools for motivated participants would balance reach with depth. Extension curricula should explicitly incorporate resilience-building content, including early-warning information interpretation, group-based risk management, and diversification planning, alongside the traditional focus on agronomic techniques.

Future research should pursue three directions. Randomised controlled trials comparing resilience outcomes across extension modalities would provide the causal evidence that this cross-sectional design cannot deliver. Cost-effectiveness analysis would clarify whether the higher per-farmer cost of farmer field schools is justified by proportionally higher resilience returns. And replication across other rice-producing zones in West Africa particularly in Nigeria, Sierra Leone, and Senegal would test the generalisability of the modality ranking observed in Ghana and inform regional extension investment strategies under the Comprehensive Africa Agriculture Development Programme.

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Contributions not qualifying for authorship

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