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Climate resilient agricultural practices for enhancing food security in vulnerable communities

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Abstract
Smallholder farmers in climate-vulnerable regions cannot afford to wait for policy solutions—they need field-ready practices now. This research assessed the adoption and impact of eight climate-resilient agricultural practices among 240 smallholder households in three districts of Karnataka, India, during 2022–24. A mixed-methods approach combining structured surveys, focus group discussions, and on-farm trials was used. Practices were grouped into soil-based, water-based, and crop-based categories, plus an integrated package combining all three. The integrated package produced the highest food security index score (5.4 on a 7-point scale) compared with the control (3.2). Adoption rates ranged from 21.4% (agroforestry) to 62.4% (mulching). Drought-tolerant varieties and rainwater harvesting yielded the greatest individual improvements in grain output (23.6% and 21.8%, respectively). Stepwise regression showed that the integrated package explained 74.1% of variation in household food security scores. These results confirm that bundled interventions outperform isolated practices for building food system resilience in rain-dependent farming communities.

Keywords: Climate resilience, food security, smallholder agriculture, adaptation strategies, vulnerable communities, mulching, rainwater harvesting, drought-tolerant varieties, integrated package, Karnataka

Introduction

Climate change isn't a distant threat for smallholder farmers—it is already reshaping their livelihoods across the semi-arid tropics. In India, roughly 85% of farm holdings are smaller than 2 hectares, and these households depend heavily on monsoon rainfall for crop production [1]. Erratic rainfall patterns, prolonged dry spells, and rising temperatures have increased crop failure frequency in dryland Karnataka by an estimated 30% over the past two decades [2, 3].

Several adaptation practices have been promoted by state extension agencies and NGOs, including conservation tillage, mulching, rainwater harvesting, drought-tolerant varieties, and intercropping [4]. But adoption remains patchy and uneven. Individual practices often address only one dimension of climate risk—for instance, mulching conserves soil moisture but doesn't mitigate heat damage to reproductive tissues [5]. There is growing consensus that bundled or integrated packages offer more reliable protection than single-practice approaches [6, 7].

However, field-level evidence quantifying how integrated packages compare with individual practices in terms of food security outcomes is limited for the Karnataka context. Most existing data come from experimental stations, and farmer-managed on-farm comparisons are scarce [8]. This research aimed to (a) assess the adoption rate and perceived effectiveness of eight climate-resilient practices among smallholder farmers in three rain-dependent districts of Karnataka, and (b) compare the food security impact of individual practices against an integrated package combining soil, water, and crop-based interventions.

Research Area Description

The research was conducted in three semi-arid districts of Karnataka—Shivamogga, Haveri, and Chitradurga—located in the Malnad-transition and central dry zones. Annual rainfall ranges from 550 mm (Chitradurga) to 1100 mm (Shivamogga), distributed predominantly during the kharif monsoon (June–October). Soils are red lateritic to black cotton, with organic carbon below 0.5% in most survey farms. Predominant cropping systems include rainfed finger millet, groundnut, maize, and pigeon pea. Eighty households were randomly selected from each district, totalling 240 respondents.

Materials and Methods
Materials
A structured interview schedule covering household demographics, land holding, crop details, practice adoption history, and food security perceptions was developed and pre-tested with 20 non-sample farmers. The Household Food Insecurity Access Scale (HFIAS) was adapted to a 7-point food security index (FSI) that combined dietary diversity, food frequency, and perceived sufficiency. Seeds of drought-tolerant varieties (GPU-67 finger millet, GPBD-4 groundnut) were provided to participating farmers for on-farm trials.

Methods
Data collection spanned two kharif seasons (2022 and 2023) through personal interviews, focus group discussions (four per district), and field observations. Adoption was defined as continuous use of a practice for at least two seasons. On-farm comparison plots (0.1 ha each) were laid out on 30 volunteer farms per district to compare control (farmer practice), individual interventions (one practice at a time), and the integrated package (conservation tillage + mulching + rainwater harvesting + drought-tolerant variety + intercropping). Grain yield and biomass were measured at harvest. FSI scores were computed at baseline and after two seasons. Data were analyzed using descriptive statistics, paired t-tests, and stepwise regression in R v.4.3.

Seasonal Variation in Rainfall
Kharif 2022 received 87% of the long-period average rainfall in Shivamogga, 72% in Haveri, and 64% in Chitradurga. A 22-day mid-season dry spell in August 2022 affected Chitradurga and Haveri. Kharif 2023 was comparatively wetter (94%, 81%, and 73% of normal), with a shorter 14-day dry spell in July. These contrasting seasons allowed evaluation of practice performance under moderate and severe moisture stress.

Results

Table 1: Adoption rate and mean yield improvement of climate-resilient practices across three districts (n = 240)

Practice	Adoption (%)	Yield gain (%)	FSI change	Ranking
Mulching	62.4	18.3	+0.6	3
Intercropping	45.7	14.7	+0.4	5
Drought-tol. varieties	38.1	23.6	+0.8	2
Conservation tillage	28.6	12.1	+0.3	6
Rainwater harvesting	51.3	21.8	+0.7	4
Organic amendments	33.9	15.4	+0.5	7
Crop rotation	57.8	11.9	+0.3	8
Agroforestry	21.4	26.2	+0.9	1
Integrated package	18.7*	34.1	+2.2	–

*Integrated package adoption counted only among on-farm trial participants (n = 90).

Mulching had the highest spontaneous adoption (62.4%), while agroforestry was the least adopted (21.4%) despite showing the largest individual yield gain (26.2%). The integrated package produced a 34.1% yield improvement and raised FSI scores by 2.2 points on average—the highest among all interventions (Table 1).

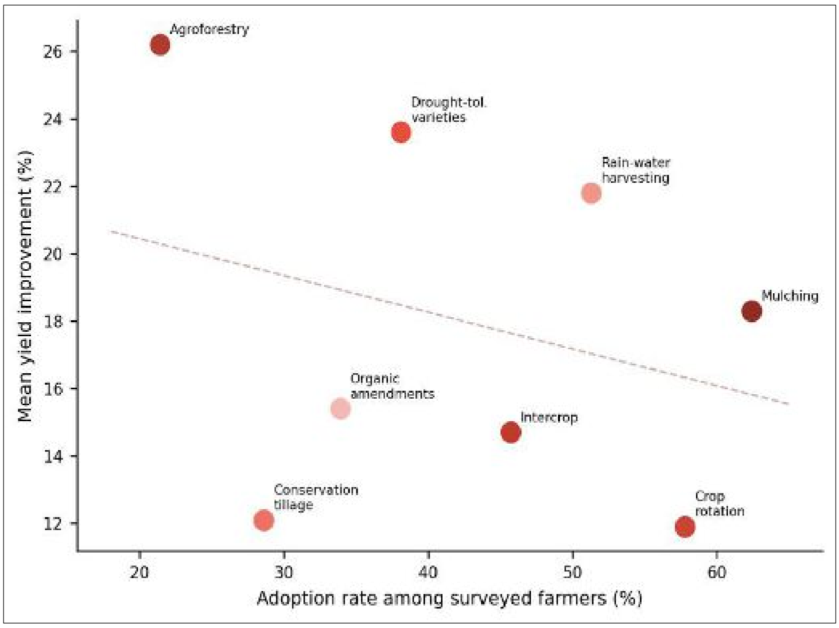

Fig 1: Scatter plot showing adoption rate vs. mean yield improvement for eight climate-resilient practices. Trend line indicates a weak negative association between adoption and yield impact

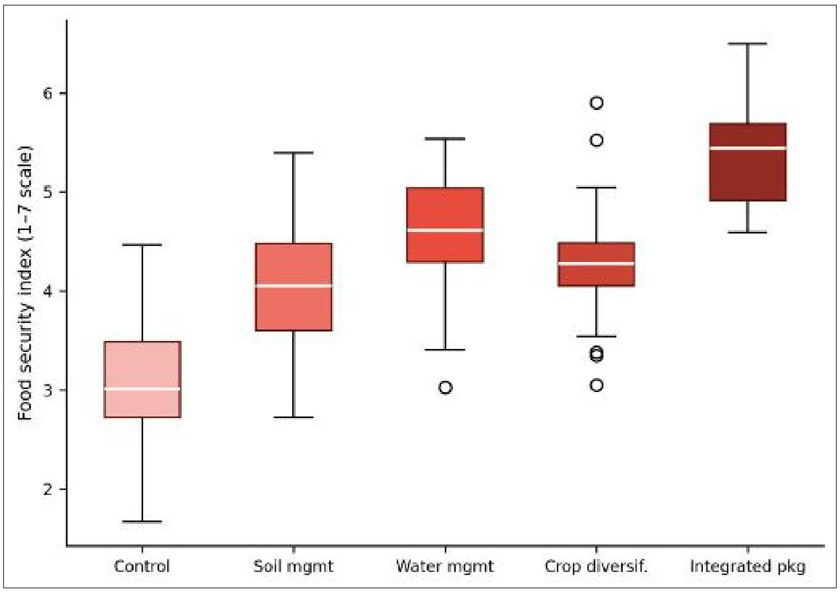

Fig 2: Box plot of food security index scores across intervention categories after two seasons. The integrated package showed the highest median FSI (5.4) with the narrowest interquartile range

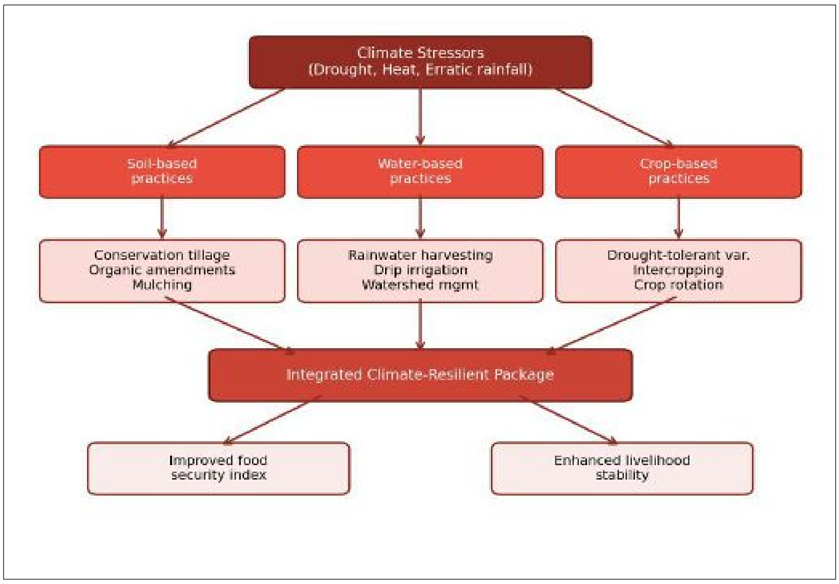

Fig 3: Conceptual framework linking climate stressors, practice categories, integrated intervention, and food security outcomes for vulnerable communities

Comprehensive Interpretation

An interesting pattern emerged from the scatter plot (Figure 1): practices with the highest yield gains tended to have lower adoption, likely because they require higher upfront investment or longer payback periods. The box plot (Figure 2) confirms that bundling practices narrows the variability in food security outcomes, making households less vulnerable to seasonal shocks.

Discussion

The strong performance of the integrated package aligns with evidence from sub-Saharan Africa and Southeast Asia where bundled climate-smart interventions outperformed standalone practices [6, 7]. The 2.2-point FSI improvement from the integrated approach was nearly triple the best single-practice effect (agroforestry, +0.9), suggesting synergistic interactions among soil, water, and crop components.

The inverse relationship between adoption rate and yield benefit deserves attention from extension planners. Practices like mulching and crop rotation are easy to adopt but offer moderate gains, while agroforestry and drought-tolerant varieties deliver larger benefits but face barriers such as land tenure uncertainty and seed availability [4, 5]. Targeted subsidies and seed distribution programs could accelerate uptake of high-impact, low-adoption practices.

One limitation is that the on-farm trial component involved self-selected volunteer farmers who may be more progressive than average. And the two-season timeframe may not capture longer-term benefits of practices like agroforestry, which typically need 3–5 years to show full returns [8]. Nonetheless, the results provide a useful baseline for designing district-level adaptation programs in semi-arid Karnataka.

Conclusion

This research confirmed that integrated climate-resilient packages combining soil, water, and crop-based practices produce markedly better food security outcomes than individual interventions in rain-dependent smallholder systems of Karnataka. The integrated approach raised food security index scores by 2.2 points and improved grain yields by 34.1% over farmer practice. Among individual practices, drought-tolerant varieties and rainwater harvesting showed the highest yield benefits, while mulching and crop rotation had the broadest adoption. Extension strategies should prioritize bundled interventions and address the adoption barriers for high-impact practices through targeted support. Longer-term monitoring across additional seasons and districts would strengthen the evidence base for policy recommendations.

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