*Original Research Article*

Awareness and Key Determinants of Climate-Smart Agricultural Technologies Adoption among Smallholder Farmers in Telangana

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ABSTRACT

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| The study aimed to assess the awareness of Climate-Smart Agricultural (CSA) technologies among smallholder farmers in Telangana and identify the key factors influencing their adoption. Primary data were collected from 440 farmers, including both men and women, to understand their perceptions of climate change and CSA technologies. Descriptive statistics, such as mean and percentages, were used to analyze farmers' awareness levels, while logistic regression was applied to identify the major determinants of CSA adoption. The findings revealed that farmers in the study area had low to moderate awareness of climate change and CSA technologies. The key factors influencing adoption included knowledge of CSA, access to climate change information, and engagement with agricultural extension services. Given these findings, it was essential to enhance farmers' awareness through targeted initiatives and improve access to relevant agricultural resources to facilitate the adoption of CSA technologies. |

*Keywords: Climate Smart Agriculture, Awareness, Smallholders, Telangana*

1. INTRODUCTION

Agriculture is one of the major reasons for climate change, globally it generates 19–29 percent of total greenhouse gas (GHG) emissions especially the non-Carbon dioxide (CO2) gases methane (CH4) and nitrous oxide (N2O) comprise a uniquely large share (Lynch et al., 2021, World Bank, 2021). While the Indian agriculture is also adversely impacted by the vicissitudes of climate change, that contributes 14 percent to the total GHG emissions. Within the sector, 54.6 percent of GHG emissions were due to enteric fermentation, followed by fertilizer application (19.1 %), rice cultivation (17.5%), manure management (6.7%), and residues burning (2.2%). (UNFCCC, 2021).

Under such circumstances, there is a need for adoption of sustainable farm practices to overcome the issues. Food and Agricultural Organization (FAO) has launched the concept of Climate Smart Agriculture (CSA) as an approach to guide the management of agriculture in the era of climate change during 2009, and since then has been reshaped through inputs and interactions of multiple stakeholders involved in developing and implementing the concept. The Indian Council of Agricultural Research (ICAR), Consultative Group on International Agricultural Research (CGIAR) system and various other state level institutes etc., have developed CSA technologies and approaches to assist the Indian agricultural sector to be less vulnerable to the adverse impacts of climate change (Khatri-Chhetri et al, 2017).

CSA technologies help cope up with climate change impact on agriculture by achieving goals of adaptation, mitigation and resilience. These technologies vary with location and hence, identification of area specific technologies for resilient farming is a necessity as well as a challenge. Integrated learnings through policy dialogues, stakeholder consultations, training and capacity development have potential to promote local, need based, incremental and transformative adaptation options and for expanding resilient agriculture (ICAR, IWMI and CCAFS, 2020).

India is one of the vulnerable countries to climate change in the world. Vulnerability is the propensity or predisposition to be adversely affected, it encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2022). The vulnerability Index range of Indian states is 0.42 to 0.67 (IIT Mandi & IIT Guwahati, 2020), that means almost all the states of the country are vulnerable to climate change. The Telangana state’s vulnerability index is 0.48 which comes under Semi-arid region. The state is purposively selected for the study because of the causes of GHGs increasing in the state, such as Paddy crop acreage has been increased from 19.78 million hectares (Mha) (2010-11) to 31.86 Mha (2020-21) with the highest growth rate (5.82 %) among all the states of the country. The livestock population has increased from 26.7 million in 2012 to 32.6 million in 2019, reflecting a growth rate of 22.21%, making it the second-highest state after West Bengal (23.32%). Additionally, the state has the highest average fertilizer usage in the country, at 233 kg/ha (DES, 2023). However, there is a lack of knowledge among farmers regarding climate change issues and the adoption of CSA technologies (Acharitha et al., 2022; Yuvaraj et al., 2022), and very few studies have addressed this issue. In the scenario, the present study aimed at to analyze the awareness and determinants of CSA technologies in the study area.

2. material and methods

**2.1 Data collection and analysis**

Data from 440 farmers were collected for the study from four districts of Telangana which are Nagar Kurnool, Mahbubnagar, Nirmal, and Adilabad, the districts were selected based on their vulnerability to climate change (EPTRI, 2015; Kadiyala, 2021; Ramya Sri, 2020) and the presence of interventions from the National Innovations on Climate Resilient Agriculture (NICRA) project of ICAR. A structured questionnaire was used to collect data on farmers' awareness of climate change, adoption of CSA technologies, and their interaction with agricultural extension services. Farmers were asked to express their awareness of climate change using a five-point Likert scale, where 1 represented "Strongly disagree," 2 "Agree," 3 "Neutral," 4 "Disagree," and 5 "Strongly agree." Awareness of various CSA technologies was assessed using a binary response format (Yes/No), and information was gathered on the sources of awareness and the frequency of their contact with agricultural extension institutes. Simple statistical measures such as means and percentages were used to summarize the responses.

**2.2 Econometric Model Specification**

To examine the determinants of the adoption of CSA technologies, a binary logistic regression model was utilized, given that CSA adoption is a binary variable (1 for adoption, 0 otherwise). This approach effectively estimates the probability of adoption based on a set of independent variables, encompassing socioeconomic, institutional, and perception-based factors. The analysis provides valuable insights into the key drivers shaping farmers' decisions to adopt CSA technologies. The logistic regression model is specified as follows:

Log (Pi / (1 - Pi)) = β0 + Σ βj Xij + εi

• Pi is the probability that the ith household adopts CSA technologies,

• Xij represents the jth explanatory variable,

• β0, βj are the coefficients to be estimated,

• ϵi is the error term.

**Variables in the Model:**

The dependent variable is the adoption of CSA technologies, whereas the independent variables include:

* Knowledge on CSA technologies (binary)
* Awareness of climate change (binary)
* Access to climate change information (binary)
* Gender of Household head (1 = Male, 0 = Female)
* Financial loss due to crop failure (continuous, in INR)
* Financial loss due to livestock shock (continuous, in INR)
* Market shocks experienced (binary)
* Social safety net participation (binary)
* Membership in social/community organizations (binary)
* Landholding size (continuous, in hectares)
* Educational level of household head (continuous)
* Household labor force (continuous, number of working members)
* Experience in farming (continuous, in years)
* Access to extension services (binary)

The regression results were reported in two forms: Log-odds coefficients (β) to indicate the direction and significance of relationships. Odds ratios (ORs) to provide a more intuitive interpretation of the effect size. An odds ratio greater than 1 suggests a positive influence on CSA adoption, while an odds ratio less than 1 indicates a negative effect.

3. results and discussion

**3.1 Descriptive statistics of sample farmers:**

Descriptive statistics of sample farmer are presented in Table-1

**Table 1. Descriptive statistics of sample farmers**

|  |  |  |
| --- | --- | --- |
| **S No** | **Particulars** | **Value** |
| 1 | Average age of respondents (in years) | 45.39 |
| 2 | Average experience in farming (in years) | 20.4 |
| 3 | Average landholding size (ha) | 1.36 |
| 4 | Education |  |
|  | Illiterate | 90 (20.45) |
|  | Primary (1-5) | 121 (27.50) |
|  | Secondary (6-10) | 105 (23.86) |
|  | Intermediate | 69 (15.68) |
|  | Graduate and above | 55 (12.50) |
| 5 | Number of Male headed house holds | 379 (86.13) |
| 6 | Number of Female headed house holds | 61 (13.86) |
| 7 | Total sample size | 440 (100.00) |

Figures in the parenthesis shows percentage to the total

The descriptive statistics revealed that the sample farmers had an average age of 45.39 years and a mean farming experience of 20.4 years, indicating considerable agricultural expertise. This experience may have influenced their adoption of new technologies, as younger farmers were generally more receptive to innovation than older farmers (Ali and Erenstein, 2017; Lungu, 2019). The average landholding size is 1.36 hectares, reflecting the predominance of smallholder farmers, which could impact their capacity to implement CSA practices. In terms of education, 20.45% of farmers are illiterate, while 27.50% have completed primary education, 23.86% attended secondary school, 15.68% reached the intermediate level, and 12.50% attained graduate-level education or higher, indicating that while many have basic education, fewer have advanced literacy, which may affect their ability to adopt agricultural innovations. CSA adoption is evenly split, with 50% adopters and 50% non-adopters, facilitating a comparative analysis of influencing factors. Gender disparity is evident, with 86.13% of households being male-headed and only 13.86% female-headed, highlighting the need for further exploration of gender dynamics in agricultural decision-making and CSA adoption.

**3.2 Awareness on climate change:**

Figure.1 represents the farmers’ awareness regarding various CSA technologies, as indicated by their responses to different climate-related phenomena. The responses are categorized into five levels: Strongly Agree (blue), Agree (orange), Neutral (gray), Disagree (yellow), and Strongly Disagree (dark blue). Each phenomenon related to climate change impacts and CSA awareness is analyzed below.

Farmers exhibited mixed awareness regarding extreme weather events and climate variability. For hailstorms, 26.59% agreed that it is occurring, while 30.45% strongly disagreed, reflecting diverse experiences. Similarly, awareness of floods varied, with 23.18% agreeing, 31.59% disagreeing and 17.95% strongly disagreeing, indicating that many farmers do not perceive floods as a major concern. However, groundwater depletion emerged as a widely recognized issue, with 48.41% strongly agreeing and 38.41% agreeing that water levels are declining. Temperature fluctuations were also evident, as 60.23% strongly agreed that daytime temperatures are rising, while perceptions of night-time temperature changes were more divided. Awareness of untimely rainfall was relatively high, with 33.64% strongly agreeing and 33.18% agreeing, though a small proportion remained neutral (9.77%) or disagreed (8.18%), possibly due to regional differences. Monsoon pattern changes further revealed contrasting opinions; 55.23% agreed that monsoon withdrawal is happening earlier, while 59.77% strongly agreed on delayed onset, indicating strong recognition of shifting rainfall patterns. These findings suggest that while farmers are highly aware of certain climate risks like groundwater depletion and temperature rise, perceptions of other climate events remain varied based on their localized experiences.

**Figure.1 Farmers awareness on climate change**

**3.3 Awareness on Climate Smart Agricultural technologies:**

Table-2 presents insights into farmers' awareness of various CSA technologies and their role in climate resilience. The data suggests a mixed level of awareness, with some technologies being widely recognized while others remain relatively unknown among the farming community.

**Table 2. Farmers awareness on various Climate Smart Agricultural technologies**

|  |  |  |  |
| --- | --- | --- | --- |
| **S No** | **Particulars** | **Yes (%)** | **No (%)** |
| **1** | Are you aware about the technologies involved for climate resilience? | 49.77 | 50.23 |
| **2** | Do you know drought tolerant varieties help in achieving optimum yield despite less rainfall? | 55.91 | 44.09 |
| **3** | Are you informed that direct seeded rice can reduce emission of harmful greenhouse gas? | 38.86 | 61.14 |
| **4** | Are you aware that growing green manure and incorporating into soil improves nitrogen supply and soil quality. | 51.14 | 48.86 |
| **5** | Are you aware that HDPS cotton reduces the risk of terminal drought and failure due to pests | 35.45 | 64.55 |
| **6** | Are you aware that Rooftop rain water collection provides good opportunities for augmenting the common pool of groundwater resources | 72.05 | 27.95 |
| **7** | Are you informed that farm machinery is an important intervention for timely completion of farm operations? | 87.95 | 12.05 |
| **8** | Are you aware about Automatic Weather Stations, which are issuing customized agro advisory service and improving weather literacy? | 47.05 | 52.95 |
| **9** | Do you know that site specific nutrient application and Integrated nutrient management help in bringing climate resiliency? | 40.23 | 59.77 |
| **10** | Are you aware that Crop-specific insurance to compensate income loss due to vagaries of weather. | 49.32 | 50.68 |

Table 2 presents insights into farmers' awareness of various CSA technologies and their role in climate resilience. The data suggests a mixed level of awareness, with some technologies being widely recognized while others remain relatively unknown among the farming community.

Nearly half of the farmers (49.77%) reported being aware of technologies that contribute to climate resilience, while 50.23% were unaware. This indicates a balanced division in awareness, highlighting the need for increased dissemination of knowledge on CSA technologies. In particular, 55.91% of farmers acknowledged the role of drought-tolerant varieties in maintaining optimal yields despite limited rainfall. However, a considerable percentage (44.09%) lacked awareness of this critical adaptation strategy, which is vital for climate resilience. A concerning gap is evident in the awareness of direct-seeded rice (DSR) technology, which can help reduce greenhouse gas emissions. Only 38.86% of farmers knew about this technique, while a majority (61.14%) were unaware, suggesting that the adoption of climate-friendly rice cultivation practices may be limited. Similarly, the practice of growing and incorporating green manure into the soil, which enhances nitrogen availability and improves soil quality, was known to 51.14% of farmers, while 48.86% were unaware of its benefits. Awareness about High-Density Planting System (HDPS) in cotton, which reduces risks associated with terminal drought and pest failures, was relatively low. Only 35.45% of farmers knew about HDPS, whereas a majority (64.55%) were unaware. This reflects a significant gap in knowledge about advanced agronomic practices that could enhance cotton yields in water-stressed environments. On the other hand, rooftop rainwater collection, a promising solution for groundwater augmentation, had relatively high awareness, with 72.05% of farmers recognizing its importance. However, 27.95% were still unfamiliar with this technique, suggesting room for further awareness campaigns.

The highest awareness level was observed regarding the role of farm machinery in ensuring timely farm operations, with 87.95% of farmers acknowledging its importance, while only 12.05% remained uninformed. This indicates a strong recognition of mechanization as a key strategy for climate adaptation. However, awareness about Automatic Weather Stations (AWS), which provide customized agro-advisory services, was relatively lower, with 47.05% of farmers being informed and 52.95% lacking knowledge about this crucial weather literacy tool. Site-specific nutrient management, including Integrated Nutrient Management (INM), is critical for building climate resilience, yet only 40.23% of farmers were aware of its benefits, while 59.77% were not. This reflects the need for greater emphasis on precision nutrient application techniques. Finally, awareness regarding crop-specific insurance, which helps compensate for income losses due to extreme weather events, was fairly balanced, with 49.32% of farmers being informed while 50.68% were unaware.

Overall, significant gaps observed in farmers' awareness of key CSA technologies. While knowledge about farm mechanization and water conservation techniques is relatively high, there is limited awareness about climate-friendly agronomic practices, precision nutrient management, and insurance mechanisms. This underscores the need for targeted extension programs, farmer training, and awareness campaigns to enhance the adoption of CSA technologies for improved climate resilience.

**3.4 Source of climate change/agricultural information:**

Table- 3 provides insights into the various sources of agricultural information that farmers rely on, highlighting both the strengths and gaps in information dissemination.

**Table 3. Source of information**

|  |  |  |  |
| --- | --- | --- | --- |
| **S No** | **Particulars** | **Y (%)** | **N (%)** |
| 1 | Have you ever received advice on agriculture from extension services | 89.09 | 10.90 |
| 2 | Through agriculture bulletin, newsletter or magazine | 53.40 | 46.59 |
| 3 | Through Television agricultural programmes | 60.68 | 39.31 |
| 4 | Through social media | 23.18 | 76.81 |
| 5 | Membership of Farmer’s groups or any agriculture-based initiative | 49.54 | 50.45 |

A significant majority of farmers (89.09%) reported receiving agricultural advice from extension services, demonstrating the effectiveness of formal extension mechanisms in reaching farmers with critical information on agricultural practices and climate resilience. However, a small proportion (10.90%) have never accessed extension services, suggesting potential barriers such as lack of accessibility, awareness, or engagement with agricultural extension personnel. Strengthening the reach and efficiency of these services can further enhance farmers' knowledge and adoption of improved technologies. Printed agricultural materials, such as bulletins, newsletters, and magazines, serve as an important information source for many farmers, with 53.40% stating they had accessed agricultural information through such publications. However, 46.59% of farmers had never used this medium, indicating that literacy levels, accessibility, or interest in printed materials might be limiting factors. Efforts to make such resources more engaging, simplified, and widely available could help improve their reach.

Television remains a key medium for disseminating agricultural information, with 60.68% of farmers indicating that they had received agricultural knowledge through TV programs. This suggests that agricultural broadcasts are an effective means of communication. However, 39.31% of farmers reported not using television as an information source, which could be due limited access to agriculture-focused programs, preference for other media, or reliance on personal experience and traditional knowledge. One of the most notable findings is the relatively low usage of social media as a source of agricultural information, with only 23.18% of farmers utilizing it, a significant majority (76.81%) of farmers do not use social media for agricultural knowledge, highlighting a gap in digital adoption. This may be due to challenges such as limited digital literacy, lack of awareness, or preferences for traditional sources of information. To bridge this gap, efforts should focus on improving digital engagement through user-friendly training programs, community-based WhatsApp groups, YouTube videos, and other accessible online platforms that cater to farmers' needs and existing capabilities. Membership in Farmers' Research Groups or agricultural initiatives is another potential source of information, yet the awareness and participation in such initiatives remain balanced. Around 49.54% of farmers reported being members of such groups, while 50.45% were not. This suggests that while farmer-based organizations can be effective in knowledge-sharing and collective decision-making, more efforts are needed to encourage broader participation and establish more inclusive farmer networks.

Overall, the traditional extension services and mass media, such as television and agricultural publications, continue to be the primary sources of agricultural information, digital platforms and farmer-led initiatives remain underutilized. To enhance farmers' access to CSA knowledge, it is essential to strengthen extension outreach, promote digital literacy, and encourage greater participation in farmer networks. Expanding the use of social media and mobile-based advisory services could play a crucial role in bridging the information gap and ensuring that farmers have timely access to relevant agricultural knowledge.

Figure. 2. Source of information by agent

Figure 2 highlights the primary sources of agricultural and climate change information for farmers, with government agencies being the most significant source (52.50%), followed by fellow farmers (24.55%), traders (19.09%), and NGOs (2.50%). The high reliance on government initiatives underscores the effectiveness of public-sector interventions in disseminating CSA knowledge. Peer-to-peer learning also plays a crucial role, emphasizing the need for farmer-led knowledge-sharing platforms. Traders contribute to input-related decisions, though their role in climate resilience awareness is limited. The minimal contribution of NGOs suggests the need for greater engagement. Strengthening multi-channel dissemination by integrating government services, NGOs, and peer learning mechanisms can enhance farmers’ awareness and adoption of climate-smart practices.

Figure. 3 Frequency of contact with extension institutes

Figure 3 illustrates farmers' frequency of contact with extension institutes, crucial for disseminating agricultural knowledge and climate-smart practices. The majority (47.05%) engage frequently, indicating strong reliance on extension services for updated farming information, while 24.77% interact very frequently, likely representing progressive farmers keen on continuous learning. However, 28.18% have irregular contact, possibly due to lack of awareness, accessibility issues, or reliance on alternative sources. Strengthening extension outreach through digital platforms, mobile advisories, and field visits can enhance farmer engagement, ensuring broader access to knowledge and improved adoption of CSA practices.

**3.5 Determinants of adoption of CSA technologies:**

**Table 4. Determinants of Adoption of CSA by Logistic Regression**

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Coefficient (β)** | **Odds Ratio (OR)** | ***P*-value** |
| Knowledge on CSA Technologies | 5.4269\*\*\* | 227.44 | 0.000 |
| Awareness on Climate Change | 0.1345 | 1.14 | 0.560 |
| Access to Climate Change Info | 3.0256\*\*\* | 20.61 | 0.000 |
| Male-Headed Household | -0.9409\*\* | 0.39 | 0.019 |
| Financial Loss (Crop Failure) | 0.0000375\*\* | 1.0000 | 0.041 |
| Financial Loss (Animal Shock) | -0.0000609\*\* | 0.9999 | 0.001 |
| Market Shock | -0.9728\*\*\* | 0.38 | 0.003 |
| Social Safety Nets | -0.0623 | 0.94 | 0.766 |
| Membership in Social/Community Org | -0.3492 | 0.71 | 0.225 |
| Landholding | -0.0404 | 0.96 | 0.665 |
| Educational Level of Head | 0.0198 | 1.02 | 0.565 |
| Household Labor Force | 0.3339\*\* | 1.40 | 0.013 |
| Experience in Farming | -0.0356\*\*\* | 0.97 | 0.002 |
| Availing Extension Services | 3.3021\*\*\* | 27.17 | 0.002 |
| Constant | -8.5660\*\*\* | 0.0002 | 0.000 |

If \*\*\**P*<.01, significant at 1% level; If \*\**P*<.05, significant at 5% level,

In Table-4, the logistic regression results highlight the key factors influencing CSA adoption among farmers. Knowledge of CSA technologies is the strongest determinant, increasing adoption likelihood by 227 times. Access to climate change information also significantly boosts adoption (20.61 times), while male-headed households are less likely to adopt, suggesting that female-headed households may be more proactive. Financial loss due to crop failure slightly encourages adoption, whereas livestock-related losses discourage it. Market shocks reduce adoption by 0.38 times, reflecting economic uncertainties. Household labor availability positively influences CSA uptake (1.40 times), and access to extension services significantly enhances adoption (27.17 times), reinforcing the importance of advisory support. However, factors like climate change awareness, social organization membership, social safety nets, landholding, and education level do not significantly impact adoption. These findings emphasize the need for policies focused on training, extension strengthening, and financial support to boost CSA adoption.

**4. CONCLUSION**

The study highlighted that smallholder farmers in Telangana have less or moderate awareness of CSA technologies, despite their potential to improve climate resilience. While government extension services are a key source of agricultural information, digital platforms and social media remain underutilized. The logistic regression analysis identifies knowledge of CSA, access to climate change information, and extension services as the most significant factors influencing adoption. However, financial losses, market shocks, and male-headed households show lower adoption rates, indicating structural barriers. Strengthening farmer training, extension outreach, and digital advisory services is essential to increase awareness and adoption of CSA technologies, ensuring greater resilience against climate change.

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.

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