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Climate smart agriculture technologies adoption among small-scale farmers: a case study from Gujarat, India

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In India, 78% of farmers are small and marginal, cultivating only 33% of the arable land but producing 50% of the food grain; their vulnerability to climate change poses a significant threat to the country's food security. To enhance agricultural resilience, it is crucial to understand how these farmers perceive and integrate climate-smart technologies into their farming practices. A random sample of 240 farmers was selected for this study. An ex-post facto research design was employed to investigate farmers' awareness of and adoption of CSAT and identify the significant variables influencing their decisions. The results indicate that approximately 74 per cent of farmers had low to medium awareness of CSAT, while around 83 per cent had low to medium adoption rates. Several factors were found to be significantly correlated with farmers' awareness and adoption of CSAT, including education level, annual income, exposure to agricultural mass media, participation in extension programs, innovativeness, achievement motivation, risk orientation, and scientific orientation. Additionally, farmers faced various challenges in adopting CSAT, such as the high cost of inputs, limited knowledge about CSAT, and youth migration from rural areas. Based on the study's findings, farmers emphasized the importance of involving them in decision-making processes related to the development of climate-smart technologies. They also highlighted the need for a timely supply of inputs and field visits to successful farms as effective means to promote awareness and adoption of CSAT. The comprehensive analysis of associated factors and empirical findings presented in this study will benefit private sector organizations, government extension agents, academics, and policymakers. By gaining insights into the determinants of CSAT adoption, these stakeholders can focus their efforts more effectively on promoting widespread adoption. Additionally, this study can inform policy decisions regarding the allocation of government resources to combat climate change.

KEYWORDS

agriculture, climate smart technologies, farmers, path analysis, socio-psychological factors

Introduction

Nine billion people must be fed by 2050, which will require an additional 70 per cent more food production (FAO, 2009; Godfray et al., 2010; Thomas, 2011). Global food security is increasingly threatened by climate change (Hebbsale Mallappa and Shivamurthy, 2021; Salerno et al., 2021). Climate change has several consequences, including rising temperatures, more frequent and intense extreme weather events, water shortages, rising sea levels, ocean acidification, land degradation, altered ecosystems, and a decline in biodiversity (Chand et al., 2015; FAO, 2017; Pathak et al., 2018; Raza et al., 2019; Hatfield et al., 2020; Weiskopf et al., 2020). The IPCC report, released in 2019, highlights the significant role of land degradation as a contributing factor to climate change. The report emphasizes that land degradation leads to increased greenhouse gas emissions and reduced carbon uptake rates, exacerbating the effects of climate change (Shukla et al., 2019). These factors could seriously threaten agriculture's ability to produce and feed the most vulnerable population (resource-poor small-scale farmers) and delay achieving sustainable development goals (Vågsholm et al., 2020). Research organisations, educational institutions, line departments, NGOs, and policymakers must cooperate to reduce agriculture's contributions to climate change (GHG emissions) and involve agriculture and allied sectors in finding solution for rapidly changing environmental conditions (Smith et al., 2014).

Climate variability plays a crucial role in shaping food production and farmers' income in Gujarat and Indian agriculture (Khatri-Chhetri et al., 2016). Nearly 60 per cent of yield variability can be attributed to climatic fluctuations (Lobell and Gourdji, 2012; Aryal et al., 2018; Kukal and Irmak, 2018). The impacts of climate change are evident in the sowing and crop duration (Malhi et al., 2021), as well as the intensity and duration of heat and water stress experienced by agricultural systems (Burke et al., 2015). Higher average temperatures lead to reduced radiation interception and biomass production, hampering crop growth (Zhao et al., 2017). Additionally, above-optimal temperatures directly impact the crop physiological processes.

Gujarat, being an agriculturally diverse state in India, cultivates cotton, groundnut, rice, wheat, maize and millet as major crops. These crops are significantly impacted by climate change, leading to detrimental effects on yields and overall agricultural productivity (Aryal et al., 2020). For instance, studies have shown that increased temperatures and changing rainfall patterns negatively affect cotton production, with a projected decline of up to 14 per cent in yield by 2050 (Patel et al., 2015). Groundnut, another important crop, is highly sensitive to temperature and water stress, resulting in potential yield losses of 18–20 per cent under climate change scenarios (Malhi et al., 2021). Wheat, a staple crop, faces reduced yields due to rising temperatures, with estimated losses of 4–16 per cent by 2050 (Tesfaye et al., 2017a). Similarly, millets, which are drought-tolerant crops, are also vulnerable to changing rainfall patterns and increasing temperatures, leading to possible yield reductions of 10–20 per cent (Tiwari et al., 2022). These statistics emphasize the urgent need to implement climate change adaptation strategies and promote climate-resilient agricultural practices to safeguard the productivity and sustainability of the major cropping systems in Gujarat, Anand.

Climate-smart agriculture has demonstrated its efficacy in delivering tangible benefits to farmers. According to studies, the adoption of climate-smart practices can increase farmers' incomes by up to 30 per cent and enhance crop yields by 20–30 per cent (Musafiri et al., 2021). Moreover, the implementation of climate-smart techniques has the potential to reduce greenhouse gas emissions from agriculture (Khatri-Chhetri et al., 2016) by approximately 1.5 gigatons of carbon dioxide equivalent per year (Ouédraogo et al., 2019). Additionally, the improved soil management practices associated with climate-smart agriculture can enhance soil organic carbon content by 0.3–0.6 per cent annually, contributing to better soil health and nutrient availability (Aryal et al., 2015; Khatri-Chhetri et al., 2016). These statistics highlight the substantial economic, environmental, and climate change adaptation advantages that can be achieved through the widespread adoption of climate-smart agriculture (Holden et al., 2018).

The economic viability of the agricultural production system depends on the farmer's capacity to acclimatise their farming structures in opposition to the ecological and financial stress and vagaries (FAO, 2015a; Ministry of Agriculture and Farmers' Welfare, 2015). Adaptation strategies against climate change are essential for enhancing the supply of raw materials to attain economic security and to boost net farm revenue and the raw material supply from farming and allied businesses under the climate change regime (Parajuli et al., 2019; World Bank, 2020; Gustafson et al., 2021). FAO has initiated eight action programs, such as (1) irrigation and drought management, (2) climate-resilient agricultural systems, (3) sustainable forest and land management, (4) towards effective fisheries sector, (5) improving food and livelihood security by the reducing methane emissions, (6) effective planning and allocation of funds to promote adaptation strategies towards climate change, (7) genetic diversity and climate change, and (8) saving food and avoiding waste (FAO, 2015b). CSAT enhances yield and socio-economic conditions that align with reducing GHG emissions. Hence, new farming approaches will be required to ensure food security in the face of future climate change (IPCC, 2012; Philip and Leslie, 2014; Vinaya Kumar et al., 2017).

The farmers' level of efficiency in realising net revenue and utilising resources towards mitigating climate change is based on their adaptation strategies, such as crop choice, crop diversification, efficient irrigation systems, and the introduction of livestock components (Feliciano, 2019; World Bank, 2021). Land use and water resources have a significant impact on climate change in agriculture. There are various hurdles in mitigating climate change due to limited progress in drip irrigation, aerobic cultivation, and the use of drought-tolerant crop varieties with effective root systems, as well as the persistant burning of crop residues and the lack of tree planting in wastelands and unutilised cultivable lands (Lulia, 2012; Patle, 2021).

Despite the potential benefits, the adoption of CSAT is very low in India and other developing countries. To increase the adoption of CSAT, it is essential to enhance the understanding of small and marginal farmers regarding adaptation and mitigation strategies for climate change. The rate of diffusion strategies used by the development departments significantly impacts the speed at which technology is accepted and adopted.

Additionally, a number of factors have been linked to the awareness and adoption—or non-adoption—of technologies (Scott et al., 2008; Petronilla et al., 2016). Most studies have focused on one or two dimensions of household characteristics, asset base, and farm characteristics and their influence on the adoption of CSAT (Kurgat et al., 2020; Ayat et al., 2022; Negera et al., 2022). However, the influence pattern of these factors is often complex and context-specific, depending on the location and the technologies. Although psychological and situational factors play a significant role in technology adoption, no studies have focus on these factors and their influence on the awareness and adoption of CSAT. Hence, the present study is novel in understanding the complex relationship between the socio-psychological factors and their influence on the awareness and adoption of CSAT.

The small-scale farmers in the study area are frequently affected by erratic rainfall, waterlogging problems, salinity problems, incorrect agronomic practices, and flash floods during August–September, which have led to a decrease in field crop yields, ultimately affecting farmer profits (Shaw et al., 2005; Sivakumar and Stefanski, 2010; FAO, 2011; Mehta, 2019). Studying farmers' concerns regarding knowledge, adoption, and barriers to adopting CSAT will be extremely helpful in analysing the needs and requirements of farmers. With this backdrop, the study focuses on answering the following questions and hypotheses.

Questions:

1. What is the socio-economic and psychological profile of the farmers?
2. Are farmers aware of CSAT? If yes, then up to what extent are they aware of CSAT?
3. How well do farmers cope with changing climatic scenarios by adopting CSAT?
4. What personal, social, economic, and psychological characteristics influence the farmers' awareness of and adoption of CSAT?
5. Are farmers facing any difficulties in the adoption of CSAT to mitigate the ill effects of climate change? If yes, what are their suggestions for promoting CSAT?

Hyphotheses: (H_0):

1. There is no significant relationship between the socio-economic and psychological profile of the farmers and their awareness of and adoption of Climate-Smart Agriculture Technologies (CSAT).
2. (H_0): Farmers do not face any difficulties in the adoption of CSAT to mitigate the ill effects of climate change.

Understanding the significance of the study lies in its potential to provide evidence-based recommendations and guidelines for policymakers, extension agents, and other stakeholders involved in agriculture and rural development. By identifying the factors that influence farmers' awareness and adoption of CSAT, tailored interventions and support systems can be designed to enhance climate resilience in the agricultural sector. Furthermore, addressing the difficulties faced by farmers in adopting CSAT and incorporating their suggestions into strategies for promoting these technologies will ensure the relevance and effectiveness of future climate change mitigation initiatives.

This study's findings have the potential to inform policy decisions and resource allocation, enabling targeted investments in climate-smart agricultural practices and technologies. By bridging the gap between scientific research and on-the-ground implementation, this research contributes to the broader goal of sustainable and resilient agriculture in the face of climate change. Ultimately, the significance of this study lies in its potential to facilitate transformative changes in agricultural practices, leading to improved food security, livelihoods, and environmental sustainability in Gujarat, India, and beyond.

Methodology

Study area

The investigation was conducted in Anand district (22.3299° N, 72.6151° E) of Gujarat, India. The primary crops in the district are cotton, groundnut, rice, wheat, and tobacco. Other important crops include banana, mango, lemon, papaya and other seasonal vegetables. The average size of land holdings is 0.96 Ha, and small and marginal farmers own about 30.12% of the total land area. Climate factors include temperature and precipitation, which vary greatly from season to season, with summers typically being hot and winters typically being cool. The mean maximum temperature ranges between 28.4°C during January to around 41.8°C during May, while the mean minimum temperatures fluctuate between 11.7°C during January and 27°C during June. The long-term average annual rainfall is about 799 mm. The majority of precipitation occurs between June and September during the southwest monsoon. The district has a substantial network of canals (Mahi Right Bank Canal Command Area), and it is their major source of irrigation.

For the study, the district's Agriculture Officers (AOs) were consulted to assist in selecting talukas, and they were asked to suggest villages where farmers were partially or fully adopting CSAT. In order to choose 240 farmers from 16 villages for the study area, 15 farmers were randomly chosen from each of the selected villages. The investigation was carried out using the Ex-Post-Facto research design.

Operationalisation of dependent variables

In this study, awareness refers to the first-hand information obtained by farmers about the CSAT in the farming system. Awareness is essential because it motivates individuals to obtain further information and take action. It represents the first step in the process of adoption.

A schedule was developed to assess farmers' awareness regarding CSAT. For this purpose, all relevant items about the CSAT were included, and the schedule was developed by referring to literature and consulting experts from multidisciplinary subjects of agriculture. The schedule consisted of 75 items with multiple choices, such as"Fully Aware," "Partially Aware," and "Not Aware." A score of two was assigned if the farmer was fully aware of an item, a score of one if the farmer was partially aware, and a score of zero if the farmer was not aware. The total score for each respondent was calculated accordingly. Based on their awareness scores using the mean and standard deviation, the respondents were divided into three groups.

Adoption in this study referred to the investigation of CSAT into farmers' farming practices. The technologies were selected from a package of practices and other literature reviews after discussions with subject matter specialists from Anand Agricultural University and the Gujarat state agriculture department. The scoring pattern for adoption was the same as mentioned in the awareness component.

The flow chat shows the relationship between climate change awareness, adoption of Climate-Smart Agriculture (CSA) practices, and farmers' income (Figure 1). It demonstrates the sequential steps involved, starting with increasing awareness about climate change and its impacts. From there, it shows farmers' decision-making process regarding adopting CSA practices, which can include various sustainable techniques. The flowchart highlights how adopting CSA practices can impact farmers' income through increased productivity and reduced production costs. It emphasizes the significance of

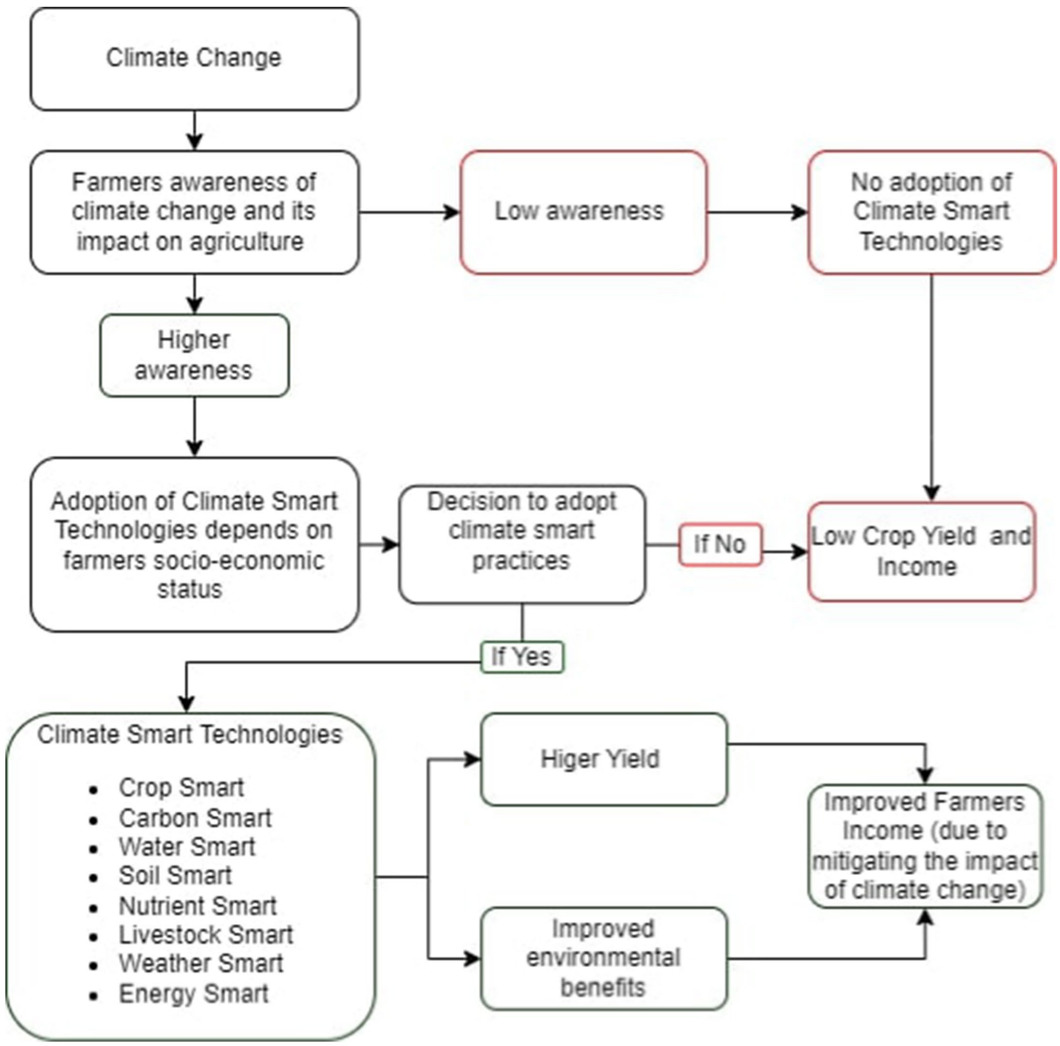

FIGURE 1
Flowchart presenting the relation among climate change awareness, adoption, CSA practices and farmers' income.

climate change awareness, adoption and sustainable farming practices in promoting farmers' income and resilience in the face of climate change challenges.

Survey data and analysis

A standardised schedule comprising all the components of CSA technologies was developed with the help of agricultural extension, agronomy, and soil science experts. The interview schedule was pre-tested in a non-sample area to identify any unclear questions, and necessary corrections were made to the final interview schedule thereafter. The data were collected through in-person interviews using a structured interview schedule to gather qualitative and quantitative information about CSA. During the household interview, the primary decision-maker for the family was questioned about several CSA traits, specifically regarding their adoption in their farming system. The collected data were analysed using appropriate statistical tools, i.e., descriptive statistics, Spearman correlation, regression, principal component analysis, and path analysis.

Path analysis

Path coefficient analysis (Wright, 1921) was used to determine the direct and indirect effects of predictive factors' on farmers' awareness and adoption of CSAT. The path co-efficient method extends the conventional partial regression coefficient method. The path analysis was carried out using SPSS software, and a diagram was developed by Drawings.net software. Path effects were obtained by solving the simultaneous equations set up for this purpose using the correlation matrix and considering one variable '1' to be influencing the other variable '1'. the simultaneous equation would be:

$$r_{yxi} = P_{yxi} r_{xixj}\ x\ p_{yxi} \quad + \sum_{i.j=1}^{n}$$

For i = 1, 2, 3, ………, n
For j = 1, 2, 3, ………, n
i.e.,
r_{yxi} = Correlation coefficient between X_i with Y,

Pyxi = Direct effect of X_i variable to Y variable, and

$\sum_{i,j=1}^{n} r_{xixj}\ x\ p_{yxi}$ = Indirect effect of the independent variable to a dependent variable *via.*, another independent variable.

Results and discussion

Socio-economic-psychological characteristics of the farmers

The information in Table 1 shows the detailed profile of respondents from the study area. Table 1 demonstrates that two-thirds of respondents (65.40%) were in the old age group, followed by the middle-aged (32.90%) category and the young (1.7%). Regarding educational level, secondary education accounts for the majority of responses (39.20%), followed by higher-secondary education (22.50%), degrees and above (20%), and primary education (18.30%). A large percentage of respondents (almost 71%) have a high degree of agricultural experience. More farmers have families that range in size from four to eight persons, followed by small families (34.17%) and large families (15.83%). Approximately 61 per cent of respondents belong to a joint family. Sixty-one and a half per cent of farmers claimed to work in agriculture and animal husbandry, while 31.25 per cent claimed to be engaged solely in the agricultural sector.

Table 1 shows that nearly two-thirds of the farmers (63.33%) are small farmers, followed by marginal farmers (36.37%). This could result from fragmented land ownership and the passing down of land from generation to generation. Over half of the respondents (51.25%) own low livestock, while high and medium livestock are owned by 25.42 per cent and 23.33 per cent of respondents, respectively.

Regarding annual income, 30 per cent of respondents are classified as high earners. Nearly two-fifths (39.60%) of respondents belong to a group with a medium degree of social participation. A higher percentage of respondents (42.90%) have low levels of exposure to agricultural media, followed by medium (35.40%) and high (21.70%) levels.

A little over two-fifths (42.50%) of the respondents have a medium level of engagement with extension services, followed by 33.30 per cent of farmers with a low level and 24.20 per cent with a high level. Two-fifths of respondents (40.40%) are classified as having a medium level of innovative proneness, followed by 32.50 per cent for low and 27.10 per cent for a high innovative proneness category.

Around 42 per cent of farmers have medium levels of achievement motivation, followed by 30.80 per cent with low and 27.10 per cent with high levels of achievement motivation. A higher percentage of farmers (46.67%) are low-risk-oriented and they also have a low level of scientific orientation (37.50%).

Psychological and economic factors significantly influence farmers' awareness and adoption of CSAT (Djufry et al., 2022; Kifle et al., 2022). However, the present study discovered that these factors, including personal, socio-economic, and psychological factors, fell into the low to medium range among the farmers. It is highly challenging to quickly improve the farmers' financial situation without addressing these traits. Nonetheless, farmers can be taught and have their positive attitudes toward CSA technologies can be changed through adequate education or capacity-building programmes, which

TABLE 1 Personal, socio-economic and psychological characteristics of the farmers (n = 240).

Characters	Category	Frequency	Per cent
Personal Variables			
1. Age	Young (less than 35 years)	4	01.70
	Middle (between 35 to 55 years)	79	32.90
	Old (More than 55 years)	157	65.40
2. Education	Primary education	44	18.30
	Secondary education	94	39.20
	Higher-Secondary education	54	22.50
	Degree and above	48	20.00
3. Farming Experience	Very Low (less than 5 years)	9	03.75
	Low (between 6 to 10 years)	27	11.25
	Medium (between 11 to 15 years)	33	13.75
	High (more than 15 years)	171	71.25
4. Family Size	Small (up to 4 members)	82	34.17
	Medium (between 5 to 8 members)	120	50.00
	Large (more than 8 members)	38	15.83
5. Family Type	Nuclear Family	94	39.20
	Joint Family	146	60.80
Socio-economic Variables			
6. Occupation	Agriculture	75	31.25
	Agriculture + livestock	147	61.25
	Agriculture + business	18	07.50
7. Land Holdings	Marginal (below 1.0 ha)	88	36.67
	Small (1.0 to 2.0 ha)	152	63.33
8. Livestock Possession	Low (≤ 2)	123	51.25
	Medium (3–5)	56	23.33
	High (≥6)	61	25.42
9. Annual Income (₹)	≤ 100,000	46	19.17
	100,001–200,000	51	21.25
	200,001–300,000	18	07.50
	300,001–400,000	26	10.83
	400,001–500,000	27	11.25
	≥500,001	72	30.00
10. Social Participation	Low	85	35.40
	Medium	95	39.60
	High	60	25.00
11. Agricultural Mass Media Exposure	Low	103	42.90
	Medium	85	35.40
	High	52	21.70

(Continued)

TABLE 1 (Continued)

Characters	Category	Frequency	Per cent
12. Extension Participation	Low	80	33.30
	Medium	102	42.50
	High	58	24.20
Psychological Variables			
13. Innovative Proneness	Low	78	32.50
	Medium	97	40.40
	High	65	27.10
14. Achievement Motivation	Low	74	30.80
	Medium	101	42.10
	High	65	27.10
15. Risk Orientation	Low	112	46.67
	Medium	65	27.08
	High	63	26.25
16. Scientific Orientation	Low	90	37.50
	Medium	74	30.80
	High	76	31.70

can lead to their decision to try and adopt the CSA technologies in their farming systems (McNamara et al., 1991; Murage et al., 2015). Therefore, efforts in this regard must be undertaken to provide farmers with the tools they need to combat the adverse effects of climate change on their farms and livelihoods (Tama et al., 2021).

Farmers' awareness of CSAT

The data in Table 2 revealed that for the first component, crop smart, the majority of the respondents (92.50%) were aware of short-duration varieties, followed by high-yielding varieties (90.83%), disease-resistant varieties (83.75%), pest-resistant varieties (83.33%), and mixed cropping (65.83%). Thus, it is evident that the farmers in the area were well aware of the varieties of crops such as banana, wheat, and other seasonal vegetables.

In the case of carbon smart, 83.75 per cent of the respondents acknowledged awareness of crop rotation awareness, followed by crop-livestock systems (70%), crop-tree-livestock systems (61.67%), agro-forestry systems (54.17%), and reduced tillage (49.58%).

According to the data in Table 2 regarding respondents' awareness of water smart practices, most of the farmers are aware of irrigation scheduling, followed by the choice of irrigation methods (76.67%), protective irrigation during critical crop stages (75.42%), micro-irrigation (7.17%), and high-value-low water use crops (61.25%).

Table 2 shows that 77.92 per cent of farmers were aware of soil smart technologies in relation to the statement "live barriers/fences," whereas 67.08 per cent were aware of mulching, 61.67 per cent were aware of planting trees, and 55.42 per cent were aware of using cover crops.

In terms of nutrient smart awareness, 88.33 per cent of respondents were aware of compost, 82.5 per cent were aware of animal manure, 80.83 per cent were aware of green manuring, 80 per cent were aware of organic fertilizer, and 76.67 per cent were aware that bio-fertilizer was used in climate-smart farming.

According to the information on livestock smart awareness in Table 2, 84.17 per cent of farmers were aware of improved feed for livestock, followed by 78.75 per cent who were aware of concentrate feeding, 68.75 per cent who were aware of treating fodder, 67.50 per cent who were aware of improved livestock health, and 60.83 per cent who were aware of improved cow breed practices.

According to Table 2, when it comes to being weather-smart, 60.42 per cent of respondents are aware of ICT services to access weather information, while 50.83 per cent are aware of for seasonal weather forecasts. In addition, 37.50 per cent are aware of protected cultivation, and 34.58 per cent are aware of index-based insurance.

In the energy-smart category, 87.50 per cent of the farmers are aware of biogas plants, followed by 67.92 per cent of the farmers are aware of residue management, 56.25 per cent are aware of solar solutions, and 46.25 per cent are aware of minimum or zero tillage systems.

It is logical to conclude from the above results that practices that are complex, highly skill-oriented and difficult to understand are least known to farmers (Ravi and Ridhima, 2019; Muhammad and Marie, 2021). On the other hand, the practices that are simple, less costly, and have being practiced by their forefathers have higher awareness among farmers.

Adaptation strategies regarding CSAT

According to the findings in the Table 2, high-yielding varieties have been adopted by 82.50 per cent of farmers, while disease-resistant varieties have been adopted by 79.17 per cent of respondents. Short-duration varieties have been adopted by 91.66 per cent of respondents, and pest-resistant varieties have been adopted by 77.50 per cent of respondents.

In the case of carbon smart, 70.42 per cent of the respondents have adopted crop rotation as an adaptation measures. Additionally, 64.17 per cent of farmers have adopted a crop-livestock system, 42.92 per cent have wisely used insecticides, 41.25 per cent have adopted reduced tillage, and 40.83 per cent have implemented a crop-tree-livestock system.

Regarding water-smart technologies, where 85.42 per cent of respondents have adopted calender-based irrigation scheduling, followed by 63.75 per cent who have used protective irrigation at crucial stages of the crop. Micro-irrigation has been adopted by 60.83 per cent of farmers, and high-value-low-water-use crop technologies have been adopted by 47,91 per cent of farmers.

In the case of soil-smart technologies, 66.66 per cent of farmers have adopted mulching, followed by 64.17 per cent who have adopted live barriers. Additionally, 52.92 per cent of them adopted tree planting, 48.33 per cent have adopted cover crops, and 47.50 per cent of farmers have adopted improved land leveling technologies in their farming systems.

Table 2 clearly indicates that compost technology has been adopted by 82.50 per cent of respondents in the case of nutrient smart technologies. Comparatively, 79.17 per cent have used animal

TABLE 2 The farmers' awareness and adoption of CSAT ($n = 240$).

Sl. No.	Content	Awareness			Adoption		
		Frequency	%	Rank	Frequency	%	Rank
Crop Smart							
1.	Short duration varieties	222	92.50	I	220	91.66	I
2.	High yielding variety	218	90.83	II	198	82.50	II
3.	Disease resistant varieties	201	83.75	III	190	79.17	III
4.	Pest resistant varieties	200	83.33	IV	186	77.50	IV
5.	Mixed cropping	158	65.83	V	127	52.92	VII
6.	Drought tolerance varieties	151	62.92	VI	132	55.00	V
7.	Direct seeded rice	136	56.67	VII	129	53.75	VI
8.	Change in cropping pattern and calendar of planting	130	54.17	VIII	92	38.33	IX
9.	Integrated farming system model	122	50.83	IX	102	42.50	VIII
10.	Reducing plant population during stress season	98	40.83	X	74	30.83	XI
11.	Contingency crop planning	97	40.42	XI	83	34.58	X
12.	Seed and fodder banks	86	35.83	XII	70	29.17	XII
Carbon Smart							
13.	Crop rotation	201	83.75	I	169	70.42	I
14.	Crop-livestock systems	168	70.00	II	154	64.17	II
15.	Crop-tree-livestock system	148	61.67	III	98	40.83	V
16.	Agro-forestry systems	130	54.17	IV	94	39.17	VII
17.	Reduced tillage	119	49.58	V	99	41.25	IV
18.	Nitrogen-fixing trees on farms	111	46.25	VI	79	32.92	VII
19.	Judicious use of insecticides	100	41.67	VII	103	42.92	III
20.	Conservation agriculture	73	30.42	VIII	49	20.42	VIII
21.	Cultivation of paddy through the SRI technique	63	26.25	IX	42	17.50	IX
Water Smart							
22.	Calender based irrigation scheduling	210	87.50	I	205	85.42	I
23.	Choice of irrigation methods	184	76.67	II	153	63.75	II
24.	Protective irrigation during critical stages of crop	181	75.42	III	146	60.83	III
25.	Micro-irrigation	172	71.67	IV	115	47.91	IV
26.	High value-low water use crops	147	61.25	V	114	47.50	V
27.	Improved drainage management	125	52.08	VI	93	38.75	VII
28.	Water harvesting	115	47.92	VII	70	29.17	X
29.	Cover crop method	113	47.08	VIII	101	42.08	VI
30.	Judicious use of groundwater	102	42.50	IX	82	34.17	VIII
31.	Laser land levelling	94	39.17	X	71	29.58	IX
32.	Community-based water management	78	32.50	XI	47	19.58	XI
33.	Contour farming	76	31.67	XII	44	18.33	XII
Soil Smart							
34.	Live barriers/fence	187	77.92	I	154	64.17	II
35.	Mulching (crop straw, plastic, residue)	161	67.08	II	160	66.66	I
36.	Plantation of trees	148	61.67	III	127	52.92	III
37.	Use of cover crops	133	55.42	IV	116	48.33	IV
38.	Improved land levelling	128	53.33	V	114	47.50	V
39.	Grass strips along the contour of waterways	68	28.33	VI	66	27.50	VI
40.	Contour farming	47	19.58	VII	45	18.75	VII

(Continued)

TABLE 2 (Continued)

Sl. No.		Awareness			Adoption		
	Content	Frequency	%	Rank	Frequency	%	Rank
Nutrient Smart							
41.	Use of compost	212	88.33	I	198	82.50	I
42.	Use of animal manure	198	82.50	II	190	79.17	II
43.	Green manuring	194	80.83	III	179	74.58	III
44.	Organic fertiliser	192	80.00	IV	166	69.17	V
45.	Bio-fertilizer	184	76.67	V	174	72.50	IV
46.	Soil testing	166	69.17	VI	158	65.83	VI
47.	Slow-releasing nitrogenous fertiliser as neem-coated urea	152	63.33	VII	148	61.67	VII
48.	Scheduled fertiliser application	151	62.92	VIII	141	58.75	VIII
49.	Intercropping with legumes	145	60.42	IX	117	48.75	IX
50.	Integrated nutrient management	126	52.50	X	112	46.67	X
51.	Site-specific integrated nutrient management	119	49.58	XI	102	42.50	XI
52.	Leaf colour chart for checking nitrogen deficiency	107	44.58	XII	93	38.75	XII
53.	Fertigation	102	42.50	XIII	91	37.92	XIII
54.	Precision fertiliser	74	30.83	XIV	70	29.16	XIV
Livestock Smart							
55.	Improved livestock feed	202	84.17	I	157	65.42	I
56.	Concentrate feeding for livestock	189	78.75	II	145	60.42	II
57.	Fodder treatment	165	68.75	III	129	53.75	IV
58.	Improved livestock health	162	67.50	IV	132	55.00	III
59.	Improved cow breeds	146	60.83	V	110	45.83	V
60.	Improved buffalo breeds	124	51.67	VI	103	42.92	VI
61.	Improved goat breeds	49	20.42	VII	29	12.08	VII
62.	Improved poultry breeds	33	13.75	VIII	28	11.66	VIII
63.	Improved sheep breeds	32	13.33	IX	18	07.50	IX
Weather Smart							
64.	ICT services to access weather information	145	60.42	I	123	51.25	I
65.	Seasonal weather forecast	122	50.83	II	115	47.79	II
66.	Protected cultivation	90	37.50	III	59	24.58	V
67.	Climate-smart housing for livestock	73	30.42	VI	50	20.83	VII
68.	Weather-based crop advisory	76	31.67	V	66	27.50	IV
69.	Climate analogues	72	30.00	VII	54	22.50	VI
70.	Index based insurance	83	34.58	IV	74	30.83	III
Energy Smart							
71.	Biogas plant	210	87.50	I	108	45.00	II
72.	Residue management	163	67.92	II	115	47.92	I
73.	Solar solutions	135	56.25	III	58	24.17	V
74.	Minimum or zero tillage systems	111	46.25	IV	59	24.58	IV
75.	Fuel efficient engines	94	39.17	V	61	25.42	III

manure, 74.58 per cent have adopted green manure, 72.50 per cent have used biofertiliser, and 69.17 per cent have adopted organic fertiliser. Regarding livestock-smart technologies, 65.42 per cent of the farmers have adopted improved livestock feed, 60.42 per cent have adopted concentrate feeding for livestock, 55 per cent have adopted improved livestock health management practices, and 53.75 per cent have adopted fodder treatment practices in their livestock-based farming systems.

Table 2 shows that 51.25 per cent of respondents have adopted ICT services to obtain weather data, followed by 47.79 per cent who have adopted seasonal weather forecasts, and 30.83 per cent who have adopted index-based insurance.

According to the information in Table 2, around 48 per cent of the farmers have adopted residue management practices in their farming to manage the energy requirement, followed by 45 per cent who have adopted biogas plant technologies. Only 25.42 per cent of the respondents have adopted fuel efficient engines to meet the energy requirement in farming.

This kind of observation might be because farmers have resorted to using cost-effective and remunerative measures (Sivabalan and Nithila, 2018; Ravi and Ridhima, 2019; Muhammad and Marie, 2021; Mujeyi et al., 2021). Furthermore, other reasons such as extension agencies might not have educated the farmers about the CSAT, or they might have neglected these particular technologies due to their high financial investment.

A considerable number of farmers have adopted biofertilisers, organic fertilisers, weed management, and improved varieties. This certainly indicates a gradual change in the affective domain of farmers towards using fewer chemical control measures.

Farmers' overall awareness level and adoption of CSAT in their farming system

The results presented in Figure 2 indicate the levels of awareness and adoption of Climate-Smart Agriculture Technology (CSAT) among farmers. Approximately 39 per cent of the farmers exhibited a low level of awareness, while 42.50 per cent had a low level of adoption of CSAT in their farming systems. On the other hand, a medium level of awareness was observed in about one-third (34.58%) of the farmers, and 40.42 per cent fell into the medium category of adoption. Interestingly, only one fouth (26.25%) and less than one-fifth (17.08%) of the farmers demonstrated a high level of awareness and adoption of CSAT, respectively. The Chi-square value of 127.809 indicates a significant correlation between the awareness and adoption of CSA technology.

Based on these findings, it is evident that there is room for improvement in enhancing farmers' awareness and adoption of CSA technology. The results suggest that efforts should be made by the government, line departments, and universities to focus on increasing farmers' awareness of CSAT. By doing so, farmers can develop a positive attitude towards CSA technology, which, in turn, will likely encourage active implementation of CSAT on their farms (Aryal et al., 2018; Mwungu et al., 2018). This emphasis on awareness-building can lead to a more widespread and effective adoption of climate-smart agricultural practices, ultimately contributing to the sustainability and resilience of farming systems in the face of climate change.

Relationship between farmers' overall awareness of CSA technologies and their socio-psychological factors

A correlation test was conducted to examine the relationship between farmers' profile traits and their overall awareness of CSAT. The findings are presented in the Table 3. Eight factors, namely education, annual income, exposure to agricultural media, participation in extension programmes, innovative proneness, achievement motivation, risk-taking, and scientific orientation,were positively and significantly related to farmers' awareness levels at the 1 per cent level of significance. On the other hand, three factors, namely farming experience, family size, and family type,were negatively and significantly related to farmers' awareness level at 1 per cent level of significance. Other factors had tangential connections to farmers' awareness of CSA technologies.

Further, stepwise regression analysis was employed to determine the impact of the seven significantly associated variables on farmers' awareness of CSAT (as shown in Table 4). The findings revealed that these seven factors explained 48.30 per cent of the variation in farmers' CSAT awareness levels.

The results emphasize the importance of considering farmers' profile traits in efforts to enhance awareness of CSAT. By understanding the factors that influence farmers' awareness levels, policymakers and development agencies can design targeted

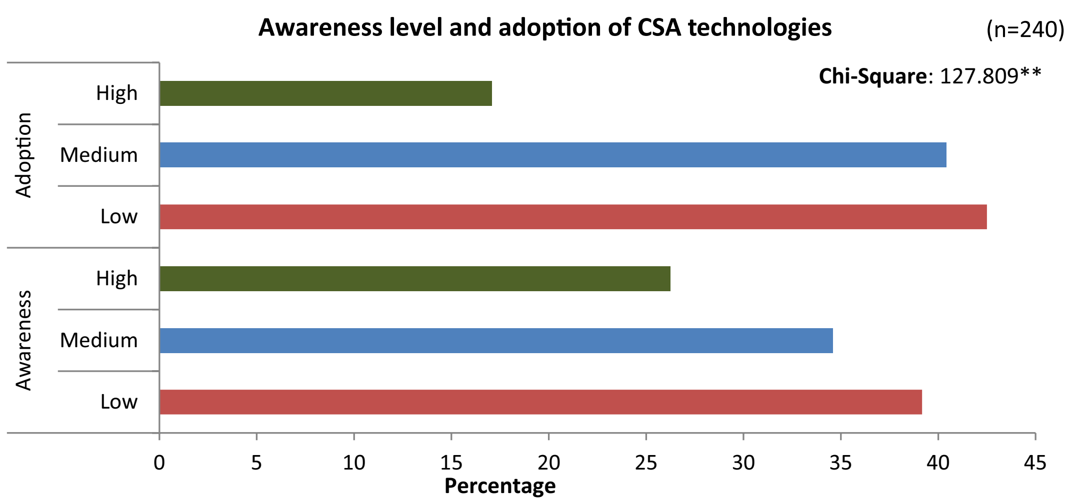

FIGURE 2
Overall farmers' awareness level and adoption of CSA technologies in their farming system. ** = significant at 0.01 per cent level.

interventions and support mechanisms to promote the adoption of climate-smart agricultural practices and contribute to the sustainable development of farming systems (Miheretu and Yimer, 2017; Chandio and Yuanshend, 2018; Mota et al., 2019).

Relationship between profile characteristics of farmers and their overall adoption of CSAT

The findings of the correlation analysis between the profile characteristics of farmers and their overall adoption level are presented in Table 5. Among the 16 variables considered in the study education, occupation, annual income, social participation, exposure to agricultural media, participation in extension programmes, innovative proneness, achievement motivation, risk orientation, and scientific orientation were positively and significantly related to the adoption level at a 0.01 per cent level of significance. On the other hand, age, agricultural experience, family size, and family type were other factors that were negatively significant at a 1 per cent level of significance.

Additionally, stepwise regression analysis was conducted to determine the impact of these 10 significantly associated variables on farmers' adoption of CSAT (as shown in Table 6). The findings revealed that out of the 10 factors, four factors explained 41.90 per cent of the variation in farmers' adoption of CSAT.

Based on these findings, it is crucial for governments and other development agencies to prioritize efforts in enhancing the profile characteristics that are significantly linked to farmers' adoption of CSAT. By focusing on improving education levels, creating job opportunities, increasing annual income, promoting social participation, enhancing exposure to agricultural media, facilitating participation in extension programs, and fostering characteristics such as innovative proneness, achievement motivation, risk orientation, and scientific orientation, the overall adoption of CSAT among farmers can be significantly improved. Additionally, attention should be given to addressing the negative correlations associated with age, agricultural experience, family size, and family type, as these factors hinder farmers' adoption and need to be carefully considered in adoption promotion strategies (Belay et al., 2017; Ouédraogo et al., 2019; Mujeyi et al., 2021).

The determinants of farmers' awareness and adoption of CSAT

The process of selecting elements to include in a model is a crucial issue in understanding the relationship between variable groupings. To address subjectivity and other estimation problems in conventional analysis like regression, the use of Principal Component Analysis (PCA) can provide theoretically and statistically sound approach. PCA can also aid in understanding the regression equation. The analysis of the findings is presented in Table 7.

The analysis revealed that the first component accounts for more than 18 per cent of the variations in the possible combinations of the 16 variables. When combined, the five factors explain over 60 per cent of the overall variation. The first component implicitly demonstrates the relationship between elements related to CSA technology and psychological components. The examination of the second primary

TABLE 3 Correlation (r) between the profile of the farmers and awareness of CSA technologies (n = 240).

Sl. No.	Variable	Spearman 'r' value
1.	Age	-0.100^{NS}
2.	Education	0.302**
3.	Farming Experience	−0.171**
4.	Family Size	−0.291**
5.	Family Type	−0.236**
6.	Occupation	0.063^{NS}
7.	Land Holding	0.003^{NS}
8.	Livestock possession	−0.019^{NS}
9.	Annual Income	0.316**
10.	Social Participation	0.022^{NS}
11.	Agricultural Mass Media Exposure	0.294**
12.	Extension Participation	0.510**
13.	Innovative Proneness	0.256**
14.	Achievement Motivation	0.197**
15.	Risk Orientation	0.445**
16.	Scientific Orientation	0.373**

NS = Non-significant. **Significant at 0.01 level.

TABLE 4 Regression analysis demonstrating the relative significance of profile characteristics of farmers in determining their awareness of CSAT (n = 240).

Sr. No.	Factors	Unstandardised Coefficients		Standardised Coefficients	't' value
		B	Std. Error	Beta	
1.	Extension Participation	0.659	0.128	0.273	5.140**
2.	Risk Orientation	1.054	0.169	0.316	6.238**
3.	Agricultural Mass Media Exposure	0.809	0.218	0.185	3.715**
4.	Annual Income	9.37E-06	0.000	0.258	4.480**
5.	Innovative Proneness	0.494	0.180	0.134	2.750**
6.	Family Size	−0.457	0.195	−0.116	2.341*
7.	Land Holding	−1.010	0.469	−0.121	2.152*

R^2 = 0.483, R^2 adj = 0.467, F = 31.001**. **Significant at 0.01% level.
*Significant at 0.05% level.

component highlights the significance of economic factors (Abegunde et al., 2019; Mujeyi et al., 2019; Ouédraogo et al., 2019; Tran and Goto, 2019).

These findings highlight the importance of considering psychological and economic factors in promoting the adoption of CSA technology. Policymakers and development agencies should recognize the psychological aspects that influence farmers' decision-making processes, such as attitudes, motivations, and risk perceptions. Additionally, they should address the economic factors that affect the feasibility and profitability of adopting CSA technology.

Path effects of farmers' profile traits on their awareness and adoption of CSA technology in their farming system

According to the data presented in Tables 8, 9; Figures 3, 4, involvement in extension programs had the greatest direct positive impact on farmers' awareness of CSA technologies, followed by risk orientation and annual income. On the other hand, the adoption of CSA technologies was significantly influenced by extension contact, media exposure, and annual income. Landholding, farming experience, and social participation had the least direct impact on awareness of CSAT among the farmers. The findings suggests that factors such as family size, land ownership, and farming experience had the least direct effects on the adoption of CSA technologies by farmers.

Tables 8, 9; Figures 3, 4 also revealed that scientific orientation, achievement motivation, and education were the key factors that had the greatest indirect positive effect on farmers' awareness of CSA technologies. The adoption of CSA technology was found to have the strongest and, most favourable indirect effects on extension participation, land ownership, and scientific orientation.

The data further indicated that annual income, risk orientation, and scientific orientation had the most significant indirect effects on farmers' awareness and adoption of CSA technologies (Nyasimi et al., 2017; Tesfaye et al., 2017b; Kurgat et al., 2020). To enhance farmers' awareness and adoption of CSA technology, it is important to consider the magnitude of the direct and indirect effects of different factors and the mediator role they play. Policymakers and development agencies should prioritize efforts to increase farmers' involvement in extension programs, improve access to agricultural media, and address income disparities.

Furthermore, promoting scientific orientation and achievement motivation through education and capacity-building initiatives can also have positive indirect effects on farmers' awareness and adoption levels. Moreover, the path analysis demonstrates that although only a few variables directly influence the dependent variables of awareness and adoption, the overall effect is predominantly driven by the interrelated nature of these variables (Marenya and Barrett, 2007). This highlights the complex and interconnected dynamics involved in shaping farmers' awareness and adoption of CSA technologies.

Challenges faced by the farmers during the adoption of CSAT

Table 10 revealed that the majority of farmers (85.42%) reported that high input cost as the major restraining factor in the adoption of CSAT, followed by a lack of sufficient knowledge about the CSA technologies (75.42%), youth migration (78.50%), lack of awareness about climate change issues (70%), lack of farmers-friendly CSA technologies. These are the top five significant factors that limit farmers from adopting CSA technologies. Other constraints include the lack of legal and policy frameworks from the government (69.17%), uncertain returns (68.33%), absence of extension activities about CSA technologies (68.33%), lack of knowledge about adaptive practices of CSA (65.83%), poor information dissemination about the technologies (65.42%), non-availability of labour for the adoption of CSAT (65.00%), small landholding (64.58%), lack of access to credit (62.50%), absence of subsidies on planting materials (62.08%), delayed availability of inputs (61.67%), limited marketing access (59.58%), inadequate assistance from national and local authorities on climate-related issues (56.25%), lack of improved communication facilities (54.17%), lack of farmers' organisations (49.58%), lack of necessary transportation facilities (47.08%), poor supply of uniform electricity (39.58%), and lack of irrigation facilities (39.17%).

These findings are consistent with previous studies conducted by Headey et al. (2014), Long et al. (2016), and Tsige et al. (2020), indicating a consensus on the major constraints faced by farmers in adopting CSA technologies. To address these constraints and promote the adoption of CSA technologies, policymakers and development agencies should focus on several key areas. First, efforts should be made to reduce the input costs associated with implementing CSA practices. This can be achieved through targeted subsidies, access to affordable credit, and the provision of cost-effective CSA technologies.

Second, increasing farmers' knowledge and awareness of CSA technologies through capacity-building programs, training workshops, and extension services is crucial. Providing farmers with the necessary information and skills empowers them to make informed decisions and overcome barriers related to knowledge gaps (Ogato, 2014).

Third, addressing the issue of youth migration and attracting the younger generation to farming is vital. Creating favorable conditions, such as providing support for agricultural entrepreneurship, improving rural infrastructure, and offering incentives, can encourage youth involvement in farming and increase the adoption of CSA technologies.

Fourth, strengthening legal and policy frameworks related to CSA is essential. Clear regulations, supportive policies, and incentives can create an enabling environment for farmers to adopt sustainable agricultural practices.

Overall, understanding the key constraints reported by farmers in the adoption of CSA technologies is crucial for designing effective interventions. By addressing these barriers, policymakers and development agencies can facilitate the widespread adoption of CSA practices, leading to more resilient and sustainable agricultural systems.

Farmers' suggestions to improve the adoption of CSAT

The results of Table 11 revealed that the majority of farmers (96.67%) believed that stakeholders should actively be involved in technological development. This was followed by the opinion that development organisations and line departments should ensure the availability of production inputs throughout the cropping season (87.08%). Other important factors mentioned were arranging visits to successful fields (83.75%), providing financial support for adoption and purchase of inputs (81.25%), demonstrating CSA technologies in villages (80.83%), and making improved crop variety seeds available in the village (77.08%).

These findings align with previous studies conducted by Jirata et al. (2016), Abera et al. (2020), and Hariharan et al. (2020), suggesting a consensus among farmers regarding the importance of stakeholder involvement and the measures needed to promote the adoption of CSA technologies.

To effectively address the farmers' perspectives and recommendations, it is crucial to raise awareness among the farming community about climate change and the advancements in CSA technologies. Farmers need to be informed and educated about the benefits and practices of CSA and the importance of sustainable land-use practices. Additionally, farmers should be encouraged to actively participate in technology development and decision-making processes, as their insights and experiences are vital for the successful implementation of CSA initiatives. It is particularly important to consider the specific requirements and challenges faced by small, marginal, and resource-poor farmers, who may require additional support and tailored approaches to ensure their inclusion in CSA programs.

TABLE 5 Correlation analysis between the profile of the farmers and the adoption of CSAT by farmers' (*n* = 240).

Sl. No.	Variable	Spearman value ('r')
1.	Age	−0.182**
2.	Education	0.255**
3.	Farming Experience	−0.175**
4.	Family Size	−0.300**
5.	Family Type	−0.200**
6.	Occupation	0.182**
7.	Land Holding	0.116[NS]
8.	Livestock possession	0.130*
9.	Annual Income	0.450**
10.	Social Participation	0.179**
11.	Agricultural Mass-media Exposure	0.312**
12.	Extension Participation	0.464**
13.	Innovative Proneness	0.221**
14.	Achievement Motivation	0.251**
15	Risk Orientation	0.184**
16.	Scientific Orientation	0.219**

NS = Non-significant. **Significant at 0.01 level.
*Significant at 0.05 level.

Conclusion

1. The majority of farmers in the study area exhibit a high level of awareness and adoption of crop-smart practices, such as short-duration and high-yielding crop varieties, indicating their knowledge of improved agricultural techniques.
2. Farmers show relatively lower awareness and adoption levels in certain areas of climate-smart agriculture, such as energy-smart and weather-smart technologies. Continuous learning about CSAT, climatic information, and agro-advisory services should be prioritised for farmers, financial institutions, and input service providers. This will enhance farmers' capacity to adapt to climate change while also changing their perspectives on climate-smart farming. Although, our study focused on India, the conclusions drawn can be applicable to other countries that seek to increase agricultural output while minimising the negative impact of climate change.
3. It is evident that governments and other development agencies should prioritize efforts to enhance the profile traits that are significantly linked to farmers' awareness of CSAT. By focusing on improving education levels, increasing income opportunities, promoting exposure to agricultural media, facilitating participation in extension programs, and fostering characteristics such as innovative proneness, achievement motivation, risk-taking, and scientific orientation, the overall awareness of CSAT among farmers can be significantly improved. Additionally, attention should be given to addressing the negative correlations associated with farming experience, family size, and family type, as these factors hinder farmers' awareness and need to be carefully considered in awareness-building initiatives.
4. Constraints hindering the adoption of CSA technologies include high input costs, lack of knowledge, youth migration, and limited awareness about climate change issues. Addressing

TABLE 6 Regression analysis demonstrating the relative significance of profile characteristics of farmers in determining their adoption of CSAT (*n* = 240).

Sr. No.	Factors	Unstandardised Coefficients		Standardised Coefficients	't' value
		B	Std. Error	Beta	
1.	Extension Participation	0.790	0.133	0.314	5.921**
2.	Annual Income	1.38E-05	0.000	0.363	7.143**
3.	Family Size	−0.802	0.209	−0.196	3.832**
4.	Agricultural Mass Media Exposure	0.749	0.236	0.164	3.174**

R^2 = 0.419., R^2 adj = 0.409, F = 42.345. **Significant at 0.01% level.

TABLE 7 Contribution of factors on awareness and adaption of CSAT ($n = 240$).

Sl. No.	Components	Components				
		1	2	3	4	5
	Eigen root	**2.882**	**2.323**	**1.82**	**1.441**	**1.283**
	% Variation expressed	**18.011**	**14.521**	**11.376**	**9.007**	**8.016**
	Cumulative variation expressed	**18.011**	**32.532**	**43.908**	**52.915**	**60.93**
1.	Age	−0.378	−0.556	0.250	0.353	0.306
2.	Education	**0.571**	0.179	−0.215	−0.029	−0.370
3.	Farming Experience	−0.406	−0.433	0.371	**0.546**	0.245
4.	Family Size	−0.513	0.097	**0.518**	−0.187	−0.398
5.	Family Type	−0.550	0.191	0.471	−0.224	−0.324
6.	Occupation	0.019	**0.609**	−0.166	0.244	0.176
7.	Land Holding	0.118	0.392	0.359	0.503	−0.281
8.	Livestock possession	−0.090	0.496	0.297	0.270	0.264
9.	Annual Income	0.333	**0.572**	0.241	0.474	−0.111
10.	Social Participation	0.061	0.375	**0.501**	−0.429	0.376
11.	Agricultural Mass Media Exposure	0.397	0.260	0.128	−0.411	0.257
12.	Extension Participation	**0.657**	−0.102	0.370	−0.158	0.258
13.	Innovative Proneness	0.293	0.004	−0.074	0.263	**0.575**
14.	Achievement Motivation	0.478	−0.201	0.469	−0.113	−0.065
15.	Risk Orientation	**0.559**	−0.421	0.098	0.191	−0.328
16.	Scientific Orientation	**0.575**	−0.462	0.377	0.065	−0.096

Bold values mean important factors in each component.

TABLE 8 Path effect of selected characteristics of the farmers on awareness about CSA technologies ($n = 240$).

Sr. No.	Factors	Total Direct effect	Total Indirect effect	Substantial effect	
				1	2
X1	Age	0.0741	−0.1744	0.0084 (X10)	0.0073 (X7)
X2	Education	0.0896	0.2120	0.0680 (X15)	0.0495 (X12)
X3	Farming Experience	−0.0545	−0.1169	0.0437 (X1)	0.0100 (X5)
X4	Family Size	−0.1257	−0.1657	0.0487 (X5)	0.0054 (X1)
X5	Family Type	0.0766	−0.3125	0.0058 (X1)	0.0030 (X14)
X6	Occupation	0.0523	0.0104	0.0803 (X9)	0.0187 (X11)
X7	Total Landholding	−0.1219	0.1247	0.1311 (X9)	0.0105 (X2)
X8	Livestock	−0.0169	−0.0025	0.0717 (X9)	0.0151 (X6)
X9	Annual Income	0.2489	0.0668	0.0556 (X12)	0.0256 (X15)
X10	Social Participation	−0.0516	0.0734	0.0940 (X12)	0.0505 (X11)
X11	Mass Media	0.1767	0.1173	0.0773 (X12)	0.0316 (X9)
X12	Extension Participation	0.3041	0.2056	0.0874 (X15)	0.0455 (X9)
X13	Innovative proneness	0.1322	0.1234	0.0385 (X12)	0.0257 (X4)
X14	Achievement Motivation	−0.0557	0.2524	0.1171 (X12)	0.0684 (X15)
X15	Risk Orientation	0.2755	0.1697	0.0964 (X12)	0.0359 (X16)
X16	Scientific Orientation	0.0635	0.3090	0.1559 (X15)	0.1371 (X12)

these constraints, along with providing necessary support and resources, can encourage more farmers to adopt climate-smart agriculture practices.

5. Stakeholder involvement, support from development organizations and line departments, and the availability of production inputs are crucial factors for promoting the adoption

TABLE 9 Path effect of a profile of the farmers on the adoption of CSA technologies (n = 240).

Sr. No.	Factors	Total Direct effect	Total Indirect effect	Substantial effect	
				1	2
X1	Age	0.0047	−0.1871	0.0063 (X7)	0.0043 (X5)
X2	Education	0.0819	0.1726	0.0583 (X9)	0.0417 (X4)
X3	Farming Experience	0.0045	−0.1799	0.0072 (X5)	0.0028 (X1)
X4	Family Size	−0.2105	−0.0891	0.0348 (X5)	0.0091 (X10)
X5	Family Type	0.0548	−0.2553	0.0103 (X10)	0.0035 (X8)
X6	Occupation	0.0778	0.1040	0.1204 (X9)	0.0121 (X11)
X7	Total Landholding	−0.1054	0.2218	0.1965 (X9)	0.0097 (X14)
X8	Livestock	0.0243	0.1058	0.1075 (X9)	0.0225 (X6)
X9	Annual Income	0.3730	0.0774	0.0438 (X12)	0.0251 (X6)
X10	Social Participation	0.0622	0.1172	0.0741 (X12)	0.0397 (X9)
X11	Mass Media	0.1143	0.1982	0.0610 (X12)	0.0474 (X9)
X12	Extension Participation	0.2398	0.2241	0.0682 (X9)	0.0452 (X4)
X13	Innovative proneness	0.0880	0.1334	0.0431 (X4)	0.0375 (X9)
X14	Achievement Motivation	0.0999	0.1506	0.0924 (X12)	0.0204 (X11)
X15	Risk Orientation	0.0226	0.1611	0.0760 (X12)	0.0346 (X9)
X16	Scientific Orientation	0.0273	0.1916	0.1081 (X12)	0.0420 (X14)

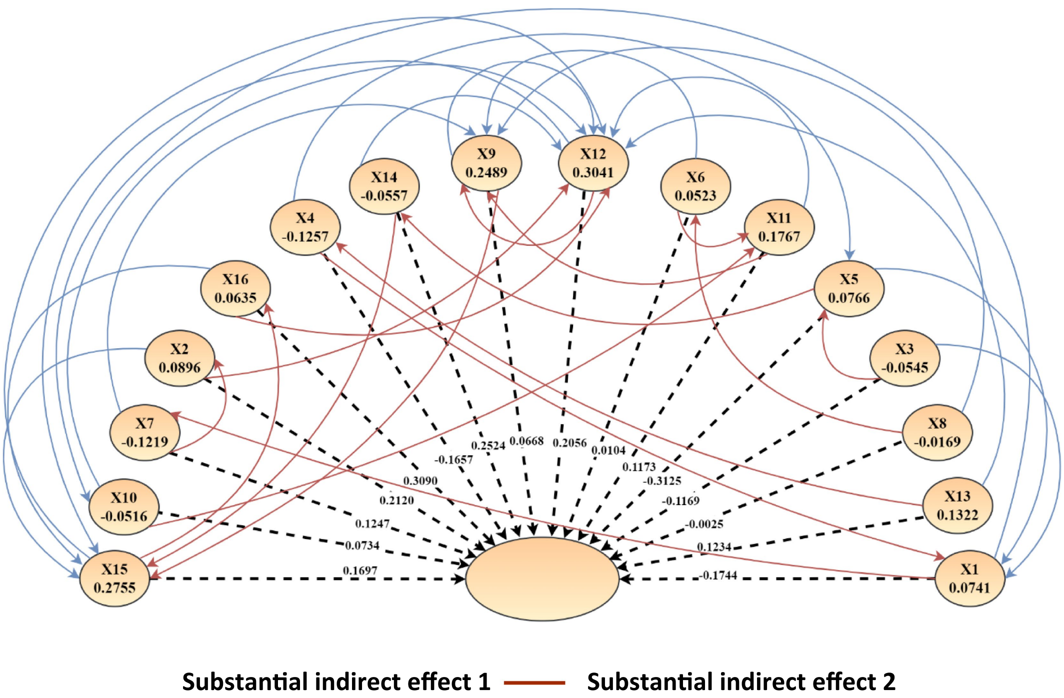

FIGURE 3
Direct and Indirect effect of characteristics of the farmers on awareness about CSA technologies.

of CSA technologies. Farmers emphasize the importance of financial support, field demonstrations, and access to improved crop variety seeds to facilitate the adoption process.

6. Principal Component Analysis (PCA) provides insights into the relationship between various factors and the overall variation in awareness and adoption of CSA technologies. Psychological components and economic factors are identified as significant contributors to farmers' awareness and adoption levels, respectively.

These conclusions highlight the current state of awareness and adoption of climate-smart agriculture technologies among farmers,

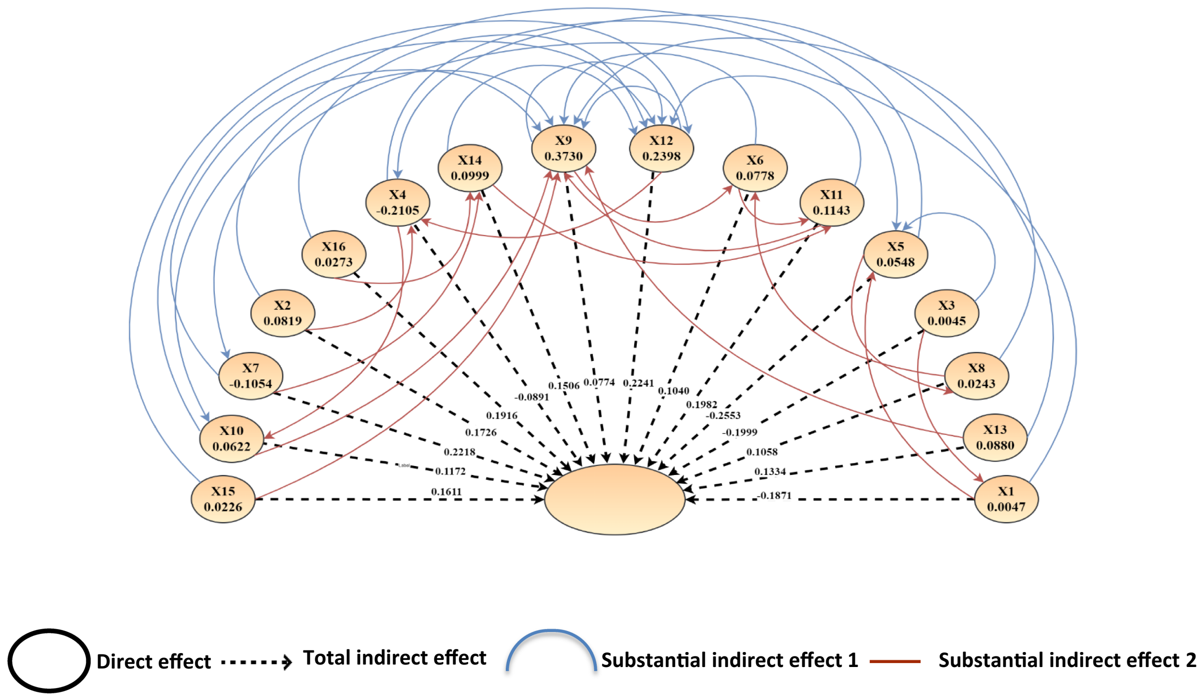

FIGURE 4
Direct and Indirect effect of characteristics of the farmers on adoption of CSA technologies.

TABLE 10 Challenges faced by the farmers in the adoption of CSAT (*n* = 240).

Sl. No.	Farmers Constraints	Frequency	Percentage	Rank
1.	High costs of inputs	205	85.42	I
2.	Lack of sufficient knowledge about the CSAT	181	75.42	II
3.	Migration of youth	180	75.00	III
4.	Lack of awareness about climate change issues	168	70.00	IV
5.	Lack of farmers-friendly CSA technologies	167	69.58	V
6.	Lack of legal and policy frameworks of government	166	69.17	VI
7.	Uncertain returns	164	68.33	VII
8.	No extension activities about CSA Technologies	164	68.33	VIII
9.	Lack of knowledge about adaptive practices of CSA	158	65.83	IX
10.	Poor information dissemination about the technologies	157	65.42	X
11.	Non-availability of labour for the adoption of CSA technologies	156	65.00	XI
12.	Small landholding	155	64.58	XII
13.	Lack of access to credit	150	62.50	XIII
14.	No subsidies on planting materials	149	62.08	XIV
15.	Non-availability of inputs on time	148	61.67	XV
16.	Limited marketing access	143	59.58	XVI
17.	Inadequate assistance from national and local authorities with climate-related issues	135	56.25	XVII
18.	Lack of improved communication facility	130	54.17	XVIII
19.	Lack of farmers' organisation	119	49.58	XIX
20.	Lack of necessary transportation facilities	113	47.08	XX
21.	Poor supply of uniform electricity	95	39.58	XXI
22.	Lack of irrigation facilities	94	39.17	XXII

TABLE 11 Farmers' suggestions for greater adoption of CSAT ($n = 240$).

Sl No	Farmers suggestions	Frequency	Percentage	Rank
1.	Farmers' participation in technological development	232	96.67	I
2.	The development organisations and line departments should make sure that production inputs are available throughout the cropping season	209	87.08	II
3.	Arranging visits to successful fields	201	83.75	III
4.	Arranging financial support for the adoption and purchase of inputs	195	81.25	IV
5.	Demonstration of CSA technologies in villages	194	80.83	V
6.	Availability of improved crop variety seeds in the village	185	77.08	VI
7.	Training on Climate Smart Agricultural technologies	181	75.42	VII
8.	Supply and availability of inputs at a cheaper price.	179	74.58	VIII
9.	Insurance must be provided for all crops.	178	74.17	IX
10.	Providing financial support for soil nutrient enrichment	150	62.5	X
11.	Showing films on Climate Smart Agricultural technologies	147	61.25	XI
12.	Group credit access	134	55.83	XII
13.	Distribution of literature on Climate Smart Agricultural technologies	112	46.67	XIII

the factors influencing their decisions, and the constraints they face. By addressing these findings, policymakers and agricultural stakeholders can develop targeted interventions and support mechanisms to promote the widespread adoption of climate-smart agriculture practices.

Data availability statement

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

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

The conceptualisation and methodology are contributions from VH and TP. VH contributed software, validation, data collection, formal analysis, and written an original draft. TP assisted in review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research 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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References

Abegunde, V. O., Sibanda, M., and Obi, A. (2019). Determinants of the adoption of climate-smart agricultural practices by small-scale farming households in king cetshwayo district municipality, South Africa. *Sustainability* 12:195. doi: 10.3390/su12010195

Abera, W., Assen, M., and Budds, J. (2020). Determinants of agricultural land management practices among smallholder farmers in the Wanka watershed, northwestern highlands of Ethiopia. *Land Use Policy* 99:104841. doi: 10.1016/j.landusepol.2020.104841

Aryal, J. P., Rahut, D. B., Maharjan, S., and Erenstein, O. (2018). Factors affecting the adoption of multiple climate-smart agricultural practices in the indo-Gangetic Plains of India. *Nat. Res. Forum* 42, 141–158. doi: 10.1111/1477-8947.12152

Aryal, J. P., Sapkota, T. E. K. B., Jat, M. L., and Bishnoi, D. K. (2015). On-farm economic and environmental impact of zero-tillage wheat: a case of north-West India. *Exp. Agric.* 51, 1–16. doi: 10.1017/S001447971400012X

Aryal, J. P., Sapkota, T. B., Khurana, R., Khatri-Chhetri, A., Rahut, D. B., and Jat, M. L. (2020). Climate change and agriculture in South Asia: adaptation options in smallholder production systems. *Environ. Dev. Sustain.* 22, 5045–5075. doi: 10.1007/s10668-019-00414-4

Ayat, U., Shahab, E. S., and Harald, K. (2022). Determinants of farmers' awareness and adoption of extension recommended wheat varieties in the Rainfed areas of Pakistan. *Sustainability* 14:3194. doi: 10.3390/su14063194

Belay, A., Recha, J. W., Woldeamanuel, T., and Morton, J. F. (2017). Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the central Rift Valley of Ethiopia. *Agric. Food Secur.* 6, 1–13. doi: 10.1186/s40066-017-0100-1

Burke, M., Hsiang, S. M., and Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature* 527, 235–239. doi: 10.1038/nature15725

Chand, R., Raju, S. S., and Reddy, A. A. (2015). Assessing performance of pulses and competing crops based on market prices and natural resource valuation. *J. Food Legumes* 28, 335–340.

Chandio, A. A., and Yuanshend, J. (2018). Determinants of adoption of improved Rice varieties in. *Rice Sci.* 25, 103–110. doi: 10.1016/j.rsci.2017.10.003

Djufry, F., Suci, W., and Renato, V. (2022). Climate smart agriculture implementation on coffee smallholders in Indonesia and strategy to accelerate. *Land* 11:1112. doi: 10.3390/land11071112

FAO (2009). High level expert forum - how to feed the world in 2050. Office of the Director, agricultural development economics division. Economic and social development department. Viale delle Terme di Caracalla, 00153 Rome, Italy.

FAO (2011). Climate change, water and food security. Rome, Italy: Sales and Marketing Group, Information Division, Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/3/i2096e/i2096e.pdf

FAO (2015a). Climate change and food security: Risks and responses. Rome, Italy: Sales and Marketing Group, Information Division, Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/3/i5188e/I5188E.pdf

FAO (2015b). The economic lives of smallholder farmers. An analysis based on household data from nine countries. Rome, Italy: Sales and Marketing Group, Information Division, Food and Agriculture Organization of the United Nations.

FAO (2017). Climate-smart crop production. Rome, Italy: Sales and Marketing Group, Information Division, Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/climate-smart-agriculture-sourcebook/production-resources/module-b1-crops/b1-overview/en/

Feliciano, D. (2019). A review on the contribution of crop diversification to sustainable development goal 1 "no poverty" in different world regions. *Sustain. Dev.* 27, 795–808. doi: 10.1002/sd.1923

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F. (2010). Food security: The challenge of feeding 9 billion people. *Science* 327, 812–818. doi: 10.1126/science.1185383

Gustafson, D., Asseng, S., Kruse, J., Thoma, G., Guan, K., Hoogenboom, G., et al. (2021). Supply chains for processed potato and tomato products in the United States will have enhanced resilience with planting adaptation strategies. *Nat. Food* 2, 862–872. doi: 10.1038/s43016-021-00383-w

Hariharan, V. K., Mittal, S., Rai, M., Agarwal, T., Kalvaniya, K. C., Stirling, C. M., et al. (2020). Does climate-Smart Village approach influence gender equality in farming households? A case of two contrasting ecologies in India. *Clim. Chang.* 158, 77–90. doi: 10.1007/s10584-018-2321-0

Hatfield, J. L., Antle, J., Garrett, K. A., Izaurralde, R. C., Mader, T., Marshall, E., et al. (2020). Indicators of climate change in agricultural systems. *Clim. Chang.* 163, 1719–1732. doi: 10.1007/s10584-018-2222-2

Headey, D., Dereje, M., and Taffesse, A. S. (2014). Land constraints and agricultural intensification in Ethiopia: a village-level analysis of high-potential areas. *Food Policy* 48, 129–141. doi: 10.1016/j.foodpol.2014.01.008

Hebbsale Mallappa, V. K., and Shivamurthy, M. (2021). Factor influencing fishery-based farmers' perception and their response to climate-induced crisis management. *Environ. Dev. Sustain.* 23, 11766–11791. doi: 10.1007/s10668-020-01141-x

Holden, S. T., Fisher, M., Katengeza, S. P., and Thierfelder, C. (2018). Can lead farmers reveal the adoption potential of conservation agriculture? The case of Malawi. *Land Use Policy* 76, 113–123. doi: 10.1016/j.landusepol.2018.04.048

IPCC (2012). Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of working groups I and II of the intergovernmental panel on climate change [field, C.B., V. Barros, T.F. stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge university press, Cambridge, UK, and New York, NY, USA, 582 pp.

Jirata, M., Grey, S., and Kilawe, E. (2016). Ethiopia climate-smart agriculture scoping study; FAO: Addis Ababa, Ethiopia, 2016.

Khatri-Chhetri, A., Aryal, J. P., Sapkota, T. B., and Khurana, R. (2016). Economic benefits of climate-smart agricultural practices to smallholder farmers in the indo-Gangetic Plains of India. *Curr. Sci.* 110, 1251–1256.

Kifle, T., Ayal, D. Y., and Mulugeta, M. (2022). Factors influencing farmers adoption of climate smart agriculture to respond climate variability in Siyadebrina Wayu District, Central highland of Ethiopia. *Clim. Serv.* 26:100290. doi: 10.1016/j.cliser.2022.100290

Kukal, M. S., and Irmak, S. (2018). Climate-driven crop yield and yield variability and climate change impacts on the U.S. great plains agricultural production. *Sci. Rep.* 8:3450. doi: 10.1038/s41598-018-21848-2

Kurgat, B. K., Lamanna, C., Kimaro, A., Namoi, N., Manda, L., and Rosenstock, T. S. (2020). Adoption of climate-smart agriculture Technologies in Tanzania. *Front. Sustain. Food Syst.* 4:55. doi: 10.3389/fsufs.2020.00055

Lobell, D. B., and Gourdji, S. M. (2012). The influence of climate change on global crop productivity. *Plant Physiol.* 160, 1686–1697.

Long, T. B., Blok, V., and Coninx, I. (2016). Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy. *J. Clean. Prod.* 112, 9–21. doi: 10.1016/j.jclepro.2015.06.044

Lulia, I. (2012). Climate-smart agriculture produces more food sustainably. International Atomic Energy Agency (IAEA), Division of Public Information. Vienna, Austria: Vienna International Centre. Available at: https://www.iaea.org/newscenter/news/climate-smart-agriculture-produces-more-food-sustainably

Malhi, G. S., Kaur, M., and Kaushik, P. (2021). Impact of climate change on agriculture and its mitigation strategies: a review. *Sustainability* 13:1318. doi: 10.3390/su13031318

Marenya, P. P., and Barrett, C. B. (2007). Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy* 32, 515–536. doi: 10.1016/j.foodpol.2006.10.002

McNamara, K. T., Wetzstein, M. E., and Douce, G. K. (1991). Factors affecting peanut producer adoption of integrated pest management. *Rev. Agric. Econ.* 13, 129–139. doi: 10.2307/1349563

Mehta, Avantika (2019). Drought-Hit Gujarat Has Water For Factories, But Not For Farmers. New Delhi, India: Indiaspend. Available at: https://www.indiaspend.com/drought-hit-gujarat-has-water-for-factories-but-not-for-farmers/

Miheretu, B. A., and Yimer, A. A. (2017). Determinants of farmers' adoption of land management practices in Gelana sub-watershed of northern highlands of Ethiopia. *Ecol. Process.* 6:19. doi: 10.1186/s13717-017-0085-5

Ministry of Agriculture and Farmers' Welfare (2015). Doubling farmers' income-volume XI. Empowering the farmers through extension. Department of Agriculture, cooperation and farmers' welfare, Ministry of Agriculture & farmers' welfare, Government of India. Available at: https://agricoop.gov.in/sites/default/files/DFI%20Volume%2011.pdf

Mota, A. A., Lachore, S. T., and Handiso, Y. H. (2019). Assessment of food insecurity and its determinants in the rural households in Damot Gale Woreda, Wolaita zone, sothern Ethiopia. *Agric. Food Secur.* 8, 1–11.

Muhammad, A. I., and Marie, J. (2021). Attitudes to climate change adaptation in agriculture – a case study of Öland, Sweden. *J. Rural. Stud.* 86, 1–15. doi: 10.1016/j.jrurstud.2021.05.024

Mujeyi, A., Mudhara, M., and Mutenje, M. J. (2019). Adoption determinants of multiple climate smart agricultural technologies in Zimbabwe: considerations for scaling-up and out. *Afr. J. Sci. Technol. Innov. Dev.* 12, 1–12.

Mujeyi, A., Mudhara, M., and Mutenje, M. (2021). The impact of climate smart agriculture on household welfare in smallholder integrated crop–livestock farming systems: evidence from Zimbabwe. *Agric. Food Secur.* 10:4. doi: 10.1186/s40066-020-00277-3

Murage, A. W., Midega, C. A. O., Pittchar, J. O., Pickett, J. A., and Khan, Z. R. (2015). Determinants of adoption of climate-smart push-pull technology for enhanced food security through integrated pest management in eastern Africa. *Food Sec.* 7, 709–724. doi: 10.1007/s12571-015-0454-9

Musafiri, C. M., Kiboi, M., Macharia, J., Ng'etich, O. K., Kosgei, D. K., Mulianga, B., et al. (2021). Adoption of climate-smart agricultural practices among smallholder farmers in Western Kenya: do socioeconomic, institutional, and biophysical factors matter? *Heliyon* 8:e08677. doi: 10.1016/j.heliyon.2021.e0867

Mwungu, C. M., Mwongera, C., Shikuku, K. M., Acosta, M., and Läderach, P. (2018). "Determinants of adoption of climate-smart agriculture Technologies at Farm Plot Level: an assessment from southern Tanzania" in *Handbook of climate change resilience*. ed. W. L. Filho (Springer International Publishing), 1–15.

Negera, M., Alemu, T., Hagos, F., and Haileslassie, A. (2022). Determinants of adoption of climate smart agricultural practices among farmers in bale-eco region, Ethiopia. *Heliyon* 8:e09824. doi: 10.1016/j.heliyon.2022.e09824

Nyasimi, M., Kimeli, P., Sayula, G., Radeny, M., Kinyangi, J., and Mungai, C. (2017). Adoption and dissemination pathways for climate-smart agriculture technologies and practices for climate-resilient livelihoods in lushoto, Northeast tanzania. *Climate* 5, 2–22. doi: 10.3390/cli5030063

Ogato, G. S. (2014). Biophysical, socio-economic, and institutional constraints for production and flow of cereals in Ethiopia. *AJHE* 3, 51–71.

Ouédraogo, M., Houessionon, P., Zougmoré, R. B., and Partey, S. T. (2019). Uptake of climate-smart agricultural technologies and practices: actual and potential adoption rates in the climate-smart village site of Mali. *Sustainability* 11:4710. doi: 10.3390/su11174710

Parajuli, R., Thoma, G., and Matlock, M. D. (2019). Environmental sustainability of fruit and vegetable production supply chains in the face of climate change: a review. *Sci. Total Environ.* 650, 2863–2879. doi: 10.1016/j.scitotenv.2018.10.019

Patel, H. R., Lunagaria, M. M., Karande, B. I., Yadav, S. B., Shah, A. V., Sood, V. K., et al. (2015). Climate change and its impact on major crops in Gujarat. *J. Agrometeorol.* 17, 190–193. doi: 10.54386/jam.v17i2.1003

Pathak, T. B., Maskey, M. L., Dahlberg, J. A., Kearns, F., Bali, K. M., and Zaccaria, D. (2018). Climate change trends and impacts on California agriculture: a detailed review. *J. Agron.* 8:25. doi: 10.3390/agronomy8030025

Patle, G. T. (2021). Climate smart water saving techniques for mitigation of climate change impacts in hill agriculture. Available at: https://www.thesangaiexpress.com/Encyc/2021/12/7/GT-PatleClimate-change-expected-to-intensify-the-demands-of-water-use-in-agriculture-as-climate-is.html

Petronilla, M., David, H., and Lyn, P. (2016). Factors contributing to adoption and use of information and communication technologies within research collaborations in Kenya. *Inf. Technol. Dev.* 22, 84–100. doi: 10.1080/02681102.2015.1121856

Philip, T., and Leslie, L. (2014). How does climate change Alter agricultural strategies to support food security? International food policy research institute (IFPRI). Washington, DC.

Ravi, S. P., and Ridhima, S. (2019). Implementing climate change adaptation: lessons from India's national adaptation fund on climate change (NAFCC). *Clim. Pol.* 19, 354–366. doi: 10.1080/14693062.2018.1515061

Raza, A., Razzaq, A., Mehmood, S. S., Zou, X., Zhang, X., Lv, Y., et al. (2019). Impact of climate change on crops adaptation and strategies to tackle its outcome: a review. *Plants* 8:34. doi: 10.3390/plants8020034

Salerno, J., Stevens, F. R., Gaughan, A. E., Hilton, T., Bailey, K., Bowles, T., et al. (2021). Wildlife impacts and changing climate pose compounding threats to human food security. *Curr. Biol.* 31, 5077–5085.e6. doi: 10.1016/j.cub.2021.08.074

Scott, S. D., Plotnikoff, R. C., Karunamuni, N., Bize, R., and Rodgers, W. (2008). Factors influencing the adoption of an innovation: an examination of the uptake of the Canadian heart health kit (HHK). *Implement. Sci.* 3:41. doi: 10.1186/1748-5908-3-41

Shaw, R., Prabhakar, S. V. R. K., and Fujieda, A. (2005). *Community level climate change adaptation and policy issues: A case study from Gujarat*, India. Graduate School of Global Environmental Studies. Kyoto University, Japan, p 59

Shukla, P.R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H. O., Roberts, D. C., et al. (2019). *An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*; IPCC: Geneva, Switzerland, 2019.

Sivabalan, K. C., and Nithila, S. (2018). Farmers' capacity strengthening and climate advisory services for combating climate change in India. *J. Pharmacogn. Phytochem.* 7, 179–182.

Sivakumar, M. V. K., and Stefanski, R. (2010). "Climate change in South Asia" in *Climate change and food security in South Asia*. eds. R. Lal, M. Sivakumar, S. Faiz, A. Mustafizur Rahman and K. Islam (Dordrecht: Springer)

Smith, P., Bustamante, M., Ahammad, H. H., Clark, H., Dong, H., Elsiddig, E. A., et al. (2014). "Agriculture, forestry and other land use (AFOLU)" in *Climate change 2014: Mitigation of climate change. Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change*. eds. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner and K. Seybothet al. (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press).

Tama, R. A. Z., Ying, L., Yu, M., Hoque, M. M., Adnan, K. M., and Sarker, S. A. (2021). Assessing farmers' intention towards conservation agriculture by using the extended theory of planned behavior. *J. Environ. Manag.* 280:111654. doi: 10.1016/j.jenvman.2020.111654

Tesfaye, K., Kassie, M., Cairns, J., Michael, M., Stirling, C., Tsedeke Abate, M., et al. (2017a). "Potential for scaling up climate smart agricultural practices: examples from sub-saharan africa" in *Climate change adaptation in Africa: Fostering resilience and capacity to adapt*. eds. W. Filho, B. Simane, J. Kalungu, M. Wuta, P. Munishi and K. Musiyiwa (Cham, AG: Springer International Publishing), 185–203.

Tesfaye, K., Zaidi, P., Gbegbelegbe, S., Boeber, C., Getaneh, F., Seetharam, K., et al. (2017b). Climate change impacts and potential benefits of heat-tolerant maize in South Asia. *Theor. Appl. Climatol.* 130, 959–970. doi: 10.1007/s00704-016-1931-6

Thomas, W. H. (2011). The global supply and demand for agricultural land in 2050: a perfect storm in the making? *Am. J. Agric. Econ.* 93, 259–275. doi: 10.1093/ajae/aaq189

Tiwari, A., Kesarwani, K., Sharma, A., Ghosh, T., Bisht, N., and Punetha, S. (2022). Drought stress in millets and its response mechanism. IntechOpen.

Tran, D., and Goto, D. (2019). Impacts of sustainability certification on farm income: evidence from small-scale specialty green tea farmers in Vietnam. *Food Policy* 83, 70–82. doi: 10.1016/j.foodpol.2018.11.006

Tsige, M., Synnevåg, G., and Aune, J. B. (2020). Gendered constraints for adopting climate-smart agriculture amongst smallholder Ethiopian women farmers. *Sci. Afr.* 7:e00250

Vågsholm, I., Arzoomand, N. S., and Boqvist, S. (2020). Food security, safety, and sustainability—getting the trade-offs right. *Front. Sustain. Food Syst.* 4:16. doi: 10.3389/fsufs.2020.00016

Vinaya Kumar, H. M., Shivamurthy, M., Govinda Gowda, V., and Biradar, G. S. (2017). Assessing decision-making and economic performance of farmers to manage climate-induced crisis in coastal Karnataka (India). *Clim. Chang.* 142, 143–153. doi: 10.1007/s10584-017-1928-x

Weiskopf, S. R., Rubenstein, M. A., Crozier, L. G., Gaichas, S., Griffis, R., Halofsky, J. E., et al. (2020). Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. *Sci. Total Environ.* 733, 137782–137718. doi: 10.1016/j.scitotenv.2020.137782

World Bank (2020). The adaptation principles: 6 ways to build resilience to climate change. Available at: https://www.worldbank.org/en/news/feature/2020/11/17/the-adaptation-principles-6-ways-to-build-resilience-to-climate-change

World Bank (2021). Climate-Smart Agriculture. Available at: https://www.worldbank.org/en/topic/climate-smart-agriculture

Wright, S. (1921). Correlation and Causation. *J. Agric. Res.* 20, 557–585.

Zhao, C., Liu, B., Piao, S., Wang, X., Lobell, D. B., Huang, L., et al. (2017). Temperature increase reduces global yields of major crops in four independent estimates. *Proc. Natl. Acad. Sci. U. S. A.* 114, 9326–9331. doi: 10.1073/pnas.1701762114