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Identification and Validation of the Antecedents and Consequences of Climate-Smart Agriculture Development Using a Meta-Synthesis

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Abstract

Climate change and intensifying drought have seriously threatened agricultural sustainability and food security worldwide, particularly in arid and semi-arid regions. Climate-smart agriculture has been proposed as an integrated approach to enhancing productivity, strengthening resilience, and reducing greenhouse gas emissions; however, evidence on the antecedents and outcomes of its development remains scattered and context-specific, and a comprehensive, validated framework is still lacking. The present study was conducted in Iran using a meta-synthesis approach in two stages. In the first stage, a systematic review was carried out based on the PRISMA checklist and the seven-step method of Sandelowski and Barroso, and out of 6,421 identified articles, 99 articles (45 Persian and 54 English) were selected to extract antecedents and outcomes. In the second stage, the Delphi technique was conducted in three rounds with the participation of 23 experts to localize and validate the findings. The results of the systematic review showed that the most important drivers include extension and advisory services, access to credit and financial facilities, government policies and support, access to modern technologies, and technical knowledge and skills, while the most important barriers include high implementation costs, weak extension services, lack of digital infrastructure, absence of supportive policies, and resistance to change. The outcomes were also categorized into three dimensions: economic (increased productivity and income), social (improved food security, reduced migration, and increased resilience), and environmental (reduced greenhouse gas emissions, improved water productivity, and carbon sequestration). The Delphi process, with Kendall's coefficient of concordance rising from 0.312 in the first round to 0.721 in the third round, achieved strong consensus, and 61 items (37 drivers and 24 barriers) were finalized. Beyond the Iranian context, the resulting framework offers a transferable diagnostic tool for identifying context-specific drivers and barriers, and provides practical guidance for designing integrated policies that combine extension capacity, targeted financing, institutional reform, digital infrastructure, and behavioral change. These findings can inform evidence-based policymaking and priority-setting for climate-smart agriculture in other drought-prone agricultural systems, contributing to the global goals of food security, climate resilience, and sustainable development.

Keywords: Food Security, Livelihood Resilience, Sustainable Development, Climate Shock.

1. Introduction

Climate change has today become a pervasive and multidimensional crisis that simultaneously threatens food security, water access, livelihood sustainability, and even the social security of communities (IPCC, 2022; WMO, 2025). Global warming and the increasing frequency and intensity of extreme events such as drought, floods, and heatwaves have reduced the performance of agricultural systems in many parts of the world (IPCC, 2023; NASA, 2025). Estimates indicate that climate change could expose more than one billion people to food crises by the end of the present century (JRC, 2026). Research evidence also shows that climate shocks directly affect the income and food security of smallholder farming households (Wollburg et al., 2024). At the same time, agriculture itself, with a significant share in greenhouse gas emissions, plays a role in intensifying this cycle (Barati et al., 2024; FAO, 2025). This situation has placed agriculture simultaneously in the position of victim and driver of climate change and has turned the transition toward more sustainable production patterns into a global necessity (Lipper et al., 2014; FAO, 2022).

Owing to its location in the world's arid and semi-arid belt, Iran is among the countries most vulnerable to climate change, and existing evidence confirms the intensification of warming and drying across the country (Mansouri Daneshvar et al., 2019; Rousta et al., 2026). Climatic analyses show that dry and wet periods in Iran have changed significantly over the past three decades, and the footprint of climate change is evident in them (Motamedi et al., 2023). Indicators related to water resources also show a concerning trend over the past three decades (Chaparinia et al., 2025). Climatic droughts have intensified in various regions of Iran and have placed heavy pressure on the agricultural sector, which is the largest water consumer in the country (Jafarpour et al., 2023; Veysi & Nouri, 2026). Studies show that climate change has affected the yield of strategic crops and the irrigation water requirements of agriculture in Iran (Karimi et al., 2018; Soltani et al., 2025). Under such conditions, Iran's food security has become heavily dependent on the adaptive capacity of the agricultural sector (Pakrooh & Kamal, 2023). However, Iranian studies show that the adoption of adaptation strategies still faces serious obstacles, and farmers' behavior is influenced by a combination of perceptual, institutional, economic, and technical factors (Yazdanpanah et al., 2014; Azadi et al., 2019; Keshavarz & Sharafi, 2023).

The agricultural regions of Iran, as important hubs of production, employment, income, and rural livelihoods, are a concrete manifestation of this crisis. Analyses of precipitation and meteorological drought trends in these regions indicate severe climatic variability and the expansion of drought (Ehsani et al., 2026; Sadeghi et al., 2025). Reduced precipitation and serious depletion of water resources have sharply reduced the capacity of dams and have seriously threatened agricultural sustainability. The consequences of these conditions are not limited to the reduction of water resources; land subsidence has also been reported as one of the chain consequences of climatic changes in these regions (Mahmoudi Cheshmehkaboud & Lashkari, 2026). In the livelihood dimension, rural households in these regions are highly vulnerable to climate change, and their sustainable livelihoods have been strongly affected by climatic conditions and water resource management (Nowruzi &

Hayati, 2015; Asadi et al., 2021). In the dimension of agricultural production, the impact of climate change on strategic crops such as wheat and maize has been documented (Khorajpour et al., 2022; Kafaei Qaeni et al., 2025). Furthermore, farmers' perception of climate change risk and their adaptive behaviors are determining factors in the adoption of innovative solutions (Qobadi Aliabadi et al., 2022; Sabounchi et al., 2023). Examination of the interrelationships among the components of climate-smart agriculture also shows that these components are intertwined and interdependent and cannot be analyzed without a systemic perspective (Asadi et al., 2021). Therefore, these agricultural systems simultaneously face climatic pressure, livelihood vulnerability, and the necessity of redesigning cropping patterns and water management, and they require a comprehensive and locally grounded solution for the transition to sustainable agriculture (Qamarnia & Nakoukish, 2025; Sayyidi Mohammadi et al., 2021).

In response to this crisis, climate-smart agriculture has been proposed as an integrated approach that simultaneously pursues three objectives: increasing productivity, strengthening resilience, and reducing greenhouse gas emissions (FAO, 2010; Lipper et al., 2014; Lipper et al., 2018). This approach has been placed on the global climate and agriculture agenda and has been introduced as a framework for redesigning production systems in developing countries (UNFCCC, 2025; Hrabanski & Le Coq, 2022; Zhao et al., 2023). However, its adoption and development in practice face institutional, economic, social, and technical barriers and are highly dependent on the local context (Karimi et al., 2024; Valipour Parkouhi et al., 2026; Ma & Rahut, 2024). Iranian studies also show that the adoption of climate-smart agriculture in Iran depends on a combination of individual, institutional, technical, and social factors, and that its barriers are diverse and context-specific (Memarbashi et al., 2022; Etemadi et al., 2025; Bakhshoudehnia et al., 2026). From a conceptual perspective, the development of this approach has both antecedents (driving, facilitating, and inhibiting factors) that shape its adoption and expansion (Nozari et al., 2026; Vasavi et al., 2025) and consequences (economic, social, environmental, and institutional outcomes) that arise from it (Simutowe et al., 2025; Mnukwa et al., 2025). However, research evidence on these antecedents and consequences is scattered, heterogeneous, and sometimes contradictory, and a systematic synthesis of them into an integrated framework has not been undertaken (Regmi & Paudel, 2024; Nshakira-Rukundo et al., 2026; Vecchio et al., 2026).

The main problem is that, despite the vital importance of developing climate-smart agriculture for Iran and its agricultural regions, no comprehensive, systematic, and validated framework of the antecedents and consequences of this development has yet been provided at the regional level. Existing studies in Iran have mostly examined one or several adoption factors or one or several outcomes in a partial and case-specific manner and do not offer a holistic picture of the constellation of antecedents and consequences (Memarbashi et al., 2022; Karimi & Ataei, 2024; Etemadi et al., 2025). This fragmentation has prevented policymakers and planners from obtaining a clear picture of priorities, relationships, and expected outcomes, making the design of locally appropriate climate-smart agriculture development programs difficult (Zhao et al., 2023; Karimi et al., 2024). Furthermore, the validation of findings from scattered studies through the opinions of experts and local stakeholders has not been carried out, and therefore the extent to which these findings correspond to regional realities remains unclear (Ahmadi et al., 2008; Keeney et al., 2001). This research gap both impedes evidence-

based policymaking and increases the risk of adopting ineffective decisions that are inconsistent with local conditions (Sandelowski & Barroso, 2003; Petticrew & Roberts, 2006).

Accordingly, the present study seeks to identify, synthesize, and validate the antecedents and consequences of climate-smart agriculture development in Iran using a meta-synthesis approach. The importance of this research lies in the fact that it moves beyond partial and case-specific examinations and provides an integrated, evidence-based, and expert-validated framework that can inform priority-setting and policymaking for climate-smart agriculture in drought-prone agricultural systems. Its novelty rests on three pillars: the systematic synthesis of scattered and heterogeneous evidence into a unified conceptual framework; the contextual validation of this framework through the structured judgment of a diverse panel of experts; and the translation of the resulting framework into actionable policy guidance that links extension capacity, targeted financing, institutional reform, digital infrastructure, and behavioral change. In doing so, the study contributes to the broader global agenda of food security, climate resilience, and sustainable development and offers a transferable analytical template for other developing countries facing comparable climatic and institutional constraints.

2. **Literature Review**

Climate-smart agriculture is an approach for transforming agricultural production systems and food value chains in order to ensure food security under climate change conditions and to support sustainable development (FAO, 2010; Lipper et al., 2014). This concept was first introduced at the 2010 Hague Conference, and FAO has played a key role in its development and promotion (FAO, 2010; Kpadonou et al., 2017). This approach pursues three objectives: sustainable increases in productivity and income (food security), adaptation and resilience to climate change, and reduction of greenhouse gas emissions (Lipper et al., 2014; FAO, 2022). The simultaneous achievement of all three objectives is not mandatory everywhere; rather, the goal is to reduce trade-offs and strengthen synergies (FAO, 2022; Bakhshoudehnia et al., 2024).

In general, climate change refers to long-term changes in weather patterns caused by human activities (IPCC, 2022) and constitutes a serious risk to farmers' livelihoods and to productivity (Karimi et al., 2018; Asadi et al., 2025). Risk perception influences adaptive behavior; farmers who perceive climate change as threatening are more likely to adopt adaptation measures (Azadi et al., 2019; Asadi et al., 2025); however, the attitude-behavior gap remains a major challenge (Yazdanpanah et al., 2014; Asadi et al., 2025).

In the literature, "antecedents" comprise driving, facilitating, and inhibiting factors with individual-psychological, economic, institutional, technical, social, and environmental dimensions (Ma & Rahut, 2024; Nozari et al., 2026), and "consequences" comprise economic, social, environmental, and institutional outcomes such as improved income, food security, resilience, water sustainability, and reduced emissions (Simutowe et al., 2025; Mnukwa et al., 2025). The development of this approach is not merely the adoption of a technology; it also includes institutional capacity-building, governance, policymaking, and the value chain (Gemtou et al., 2024; Keshavarz & Sharafi, 2023). Therefore, its systematic analysis requires the synthesis of scattered evidence within an integrated and context-

specific framework (Sandelowski & Barroso, 2003; Popay et al., 2006), which meta-synthesis and validation through expert opinion make possible (Ahmadi et al., 2008; Keeney et al., 2001).

In this regard, Nshakira-Rukundo et al. (2026), in a meta-analysis of 112 articles, found education, access to information, subsidies, and prior experience with technology to be the strongest predictors of adoption and reported an adoption rate of less than 39 percent. Vecchio et al. (2026), in a review of 58 studies, showed that local climate information leads to improved preparedness and adoption only when mediated by credible extension systems, cooperatives, access to credit, and secure land rights. Vasavi et al. (2025) identified social, economic, institutional, and ecological barriers such as limited access to credit, inadequate extension services, high initial costs, and gender inequalities, and considered financial incentives and policy support to be vital drivers. Mnukwa et al. (2025), analyzing 50 studies, reported regional differences in adoption rates, a 2.8-fold increase in adoption with extension services, a 60 percent improvement in long-term investment with land tenure security, a gender gap, and a 65 percent reduction in adoption due to high initial costs among resource-poor farmers. Billah et al. (2025) considered institutional, economic, and technological barriers to be the most important obstacles. Gemtou et al. (2024) emphasized that adoption also depends on systems, food structures, and interaction with value chain actors. Mitra and Barua (2024) found indigenous knowledge to be effective in adaptation. Ricart et al. (2023), in a review of 435 articles, identified changes in cropping patterns and soil and water conservation as the most important measures and lack of information and credit as the main barriers. Belay et al. (2023) considered effective extension services, accurate weather information, and policy support to be essential. Benson et al. (2023) found reduced greenhouse gas emissions to be among the consequences of this approach. Zhao et al. (2023) emphasized information technology, climate services, cropping patterns, and climate index-based insurance. Ogisi and Begho (2023) considered psychological, environmental, agronomic, economic, institutional, and gender factors to be influential. Asseldonk et al. (2023) identified six key practices, including water management, soil and nutrient management, stress tolerance, intercropping, crop rotation, and pest management, and demonstrated the influence of policy instruments. Oduntan and Obisesan (2022) found positive effects of marital status, access to extension services, farming experience, membership in farmers' associations, and access to credit, and negative effects of age, farm size, and income on adoption. Mazhar et al. (2021) highlighted the role of institutional factors such as contract farming and market orientation. Pagliacci et al. (2020), Zakaria et al. (2020), Khoza et al. (2020), and Filippini et al. (2020) respectively demonstrated the role of non-financial factors, training participation, social processes and gender, and social networks in adoption. Senyolo et al. (2018) considered high initial investment costs, the need for additional labor, and increased management intensity to be barriers to adoption.

Karimi & Ataei (2026), using a sixfold framework, identified systemic factors (extension services, marketing, and infrastructure) and psychological factors (environmental awareness, responsibility toward future generations, trust, and motivation) as determinants of adoption in Sistan and Baluchistan. Savari and Khaleghi (2026), using protection motivation theory, showed that the original model explains 57.9 percent of the variance in adoption and that adding social norms and habits increases explanatory power by 22 percent. Nozari et al. (2026) in Mashhad showed that farmers under

conditions of severe precipitation decline are compelled to adopt several climate-smart practices simultaneously. Mousaei (2025) found economic, social, agronomic, and individual factors to have a positive and significant relationship with the adoption of climate-smart agricultural technologies in Fars Province. Ranjbar et al. (2025) considered the integration of climate-smart principles to be an efficient tool for managing the water-food-climate nexus in semi-arid regions. Esmailnejad (2025) found adaptation to environmental conditions, reduction of climate change impacts, and modern irrigation to be the most important strategies of saffron farmers in Sarayan. Bakhshoudehnia et al. (2024) in Behbahan found the decision to use innovation, perceived usefulness, and perceived ease of use to have the greatest effect. Karimi and Ataei (2024) in the Sistan Plain found perceived usefulness, perceived ease of use, subjective norms, and attitude to be influential on the intention to apply technologies.

Tohidimoghadam et al. (2024), in a study of 380 gardeners in Hamadan Province, showed that "environmental norms" and "capacity to adapt to climatic fluctuations" have a positive and significant effect on sustainable livelihood resilience. Moreover, attitude, awareness, and environmental beliefs explained a considerable portion of the variance in resilience.

Bathaiy et al. (2024), based on semi-structured interviews with 15 local experts in the Ghezel Ozan drainage basin, showed that the factors influencing farmers' resilience to climate change fall into social, economic, human, natural, and physical capital, together with governmental, institutional-cultural, market, and multiple media factors.

Soleimani (2023) identified the difference in perception between farmers and experts as one of the main barriers to farmers' adaptation to climate change. Keshavarz and Sharafi (2023) considered scalability to require economic incentives, institutional capacity-building and local adaptation. Siyar Khalaj et al. (2022) found weak institutional trust, weak cooperation networks, information poverty, and structural barriers to be the main barriers to adaptation. Khademi Noushabadi et al. (2022) identified personal norms, subjective norms, and perceived behavioral control as the most influential variables on the intention to apply technologies related to the agricultural sector. Etemadi et al. (2022) found belief in climatic variability and risk perception to have a positive and significant effect on participation in climate-smart strategies. Amiri and Mirkzadeh (2022) in the Mahidasht Plain found perceived usefulness, perceived ease of use, and attitude to be influential on the intention to use smart water meters. Jahangirpour and Zibaei (2022) considered modern irrigation systems to be an adaptive strategy but pointed to the challenge of increased energy consumption and greenhouse gas emissions. Asadi et al. (2021), using DEMATEL, showed that increased adaptation is the most influential main component and income sustainability the most influenced, and that improved water management is the most influential sub-component. Tousi et al. (2020), using the theory of planned behavior, demonstrated the role of abstract norms and intention in optimal agricultural water consumption management.

In the agricultural regions of Iran, studies have mostly focused on livelihood vulnerability, risk perception, adaptation, and water management. Asadi et al. (2022) examined the livelihood vulnerability of rural households in these regions. Qobadi Aliabadi, et al., (2022) identified five

different types of climate change risk perception among farmers. Sabounchi et al. (2023) assessed the resilience of saffron farmers' cropping systems using the Sharp scale. Khaledi et al. (2016) identified water scarcity, neglect by officials, lack of credit, and cuts in subsidies as among the most important barriers to adaptation among wheat farmers in Sarpol-e Zahab. These studies provide valuable local grounding, but they do not offer an integrated framework of the antecedents and consequences of climate-smart agriculture development across the entire region.

A review of previous studies shows that the climate-smart agriculture literature has mainly concentrated on three axes: determinants of farmers' adoption and perception, structural and institutional barriers, and economic and environmental outcomes. However, this evidence is scattered, heterogeneous, and often case-specific and has rarely been synthesized into an integrated and validated framework. In Iran as well, studies have mostly focused on adoption, perception, adaptation barriers, or water management and have not simultaneously examined the antecedents and consequences of climate-smart agriculture development. In the agricultural regions of Iran, research has mainly investigated vulnerability, risk perception, resilience, and adaptation barriers but has not provided a comprehensive and locally grounded framework of antecedents and consequences, and the findings have not been validated through the opinions of regional experts.

Accordingly, the gap addressed by the present study is threefold. First, the existing evidence on the antecedents and consequences of climate-smart agriculture remains fragmented across disparate case studies, so that no coherent and integrated picture of the phenomenon has yet emerged. Second, the available studies have rarely translated this scattered evidence into a context-specific framework that reflects the institutional, economic, social, and environmental realities of Iran's agricultural regions. Third, the findings of prior research have not been subjected to systematic validation through the structured judgment of experts and local stakeholders, leaving their practical relevance uncertain. The present study addresses these gaps by systematically synthesizing the scattered evidence through a meta-synthesis approach, by developing an integrated and context-specific framework, and by validating that framework through expert opinion and the Delphi technique. The importance of the study lies in its capacity to move beyond partial and case-specific analyses and to provide an evidence-based, expert-validated basis for policymaking in the areas of climate adaptation, water management, extension services, credit and insurance, land tenure security, and farmer support. In doing so, it offers a transferable analytical template for prioritizing climate-smart agriculture measures in other drought-prone agricultural systems and contributes to the broader global agenda of food security, climate resilience, and sustainable development.

3-1. Study Area

The study was conducted in the agricultural systems of Iran, a country located in the world’s arid and semi-arid belt, where agriculture remains a major source of employment, income, and rural livelihoods. Iran’s agricultural sector is characterized by a high dependence on rainfed cultivation and irrigated farming, both of which are highly sensitive to precipitation variability and water availability. Over the past three decades, Iran has experienced significant changes in dry and wet periods, intensifying drought conditions, and a concerning decline in water resources, placing heavy pressure on the

agricultural sector as the largest water consumer in the country. These climatic and hydrological stresses have made Iran's food security increasingly dependent on the adaptive capacity of its agricultural systems, while the adoption of adaptation strategies continues to face institutional, economic, and behavioral barriers. The present meta-synthesis therefore focuses on this broader context of Iranian agriculture, where the interplay of climatic pressure, livelihood vulnerability, and the need for sustainable production systems is most evident, and where the antecedents and consequences of climate-smart agriculture development are of critical importance for evidence-based policymaking.

3.2. Stage One: Systematic Review

To achieve the research objective, a three-stage process was implemented: a systematic review of the literature and extraction of the initial list, and the Delphi technique for localization and validation.

A systematic review is a structured, transparent, and reproducible method for identifying, evaluating, and synthesizing existing evidence and is recognized in agricultural research as a valid method for achieving evidence-based results (Petticrew & Roberts, 2006). In this study, reporting of the review process was conducted in accordance with the 17-item PRISMA checklist, which provides a comprehensive framework for clarifying and standardizing the review stages (Moher et al., 2010). The meta-synthesis was also implemented based on the seven-step method of Sandelowski and Barroso (2003), which includes formulating the question, systematically reviewing the literature, searching for and selecting articles, extracting information, analyzing and synthesizing findings, quality control, and presenting findings. The steps of this process are presented below in order.

Step 1: Formulating the Research Question. The main review question was: "What are the antecedents (driving and inhibiting factors) and consequences (economic, social, and environmental outcomes) of climate-smart agriculture development in the global and Iranian scientific literature?"

Step 2: Search Strategy. A systematic search was conducted in international databases (Scopus, Web of Science, ScienceDirect, and Google Scholar) and domestic databases (SID, Magiran, and Noormags) using Persian and English keywords related to climate-smart agriculture, antecedents, consequences, and driving and inhibiting factors. The search strategy is presented in Table 1.

Table 1. Search Strategy in Domestic and International Databases

Search Strategy	Database
Title, Abstract and Keywords: Climate Smart Agriculture AND ('antecedent' OR 'barrier' OR 'outcome' OR 'IMPACT')	Scopus, Web of Science, ScienceDirect, Google Scholar, SID, Magiran,Noormags

Step 3: Inclusion and Exclusion Criteria. The inclusion criteria comprised studies that directly addressed the antecedents or consequences of climate-smart agriculture development, were published between 2010 and 2026, included original research articles, systematic reviews, and dissertations, and

were written in Persian or English. The exclusion criteria comprised non-systematic review articles, studies lacking sufficient empirical data, irrelevant studies, conference abstracts, and duplicate articles.

Step 4: Screening and Selection of Studies. The screening process was conducted based on the PRISMA flow diagram in four stages: identification, title and abstract screening, full-text screening, and final selection. In the initial search, 6,421 articles (6,301 Persian-language and 120 English-language) were identified. After removing 1,168 duplicate articles, 5,253 articles (5,148 Persian-language and 105 English-language) remained for initial review. In the title and abstract screening stage, 5,036 articles (4,985 Persian-language and 51 English-language) that were not directly related to the subject were excluded, and 217 articles (163 Persian-language and 54 English-language) remained for full-text review. In the final stage, 118 Persian-language articles lacking quality criteria or sufficient relevance were excluded, while all 54 remaining English-language articles met the quality criteria and were directly relevant. Ultimately, 99 articles (45 Persian-language and 54 English-language) were selected for extracting antecedents and consequences.

Step 5: Data Extraction. Data related to antecedents and consequences were extracted using a standardized data extraction form including bibliographic information (author, year, journal), research method, statistical population, and identified antecedents/consequences.

Step 6: Data Synthesis. Due to the methodological and contextual diversity of the studies, a narrative synthesis approach was used to combine qualitative and quantitative findings, which allows for the integration of findings and the discovery of complex patterns (Popay et al., 2006).

Step 7: Quality Assessment. The quality of the selected studies was assessed using standard tools: the Critical Appraisal Skills Programme (CASP) checklist for qualitative studies and the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool for quantitative studies.

The 17-item PRISMA checklist was used in this study to clarify and standardize the entire systematic review process. This checklist was developed by a group of international experts and comprises a set of minimum criteria that a systematic review must observe for transparent and complete reporting (Moher et al., 2010). Table 2 presents this checklist.

Table 2. PRISMA Checklist (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)

Reported in article	Item	Data management
		TITLE
Identification of the study as a protocol of a systematic review	1-1	Identification
If the protocol is considered an update of an existing protocol, this should be stated	2-1	Update
If registered, the name of the registry (PROSPERO) and the registration number should be stated	2	Registration
		AUTHORS
Providing the name, organizational affiliation,	3-1	Contact

email address, and telephone number of the corresponding author		
Description of protocol collaborators and introduction of the review guarantors	3-2	Contributions
If the protocol has been amended, the changes should be stated	4	Amendments
		SUPPORT
Introduction of financial sources or other support	5-1	Sources
Mention of financial sponsors	5-2	Sponsor
Description of the role of funding providers in the development of the protocol	5-3	Role of sponsor
		INTRODUCTION
Introduction of the rationale for the review in the text with respect to what is currently known	6	Rationale
Explicit statement of the research question(s)	7	Objectives
		METHODS
Identification of study characteristics (design, year, publication status) as eligibility criteria	8	Eligibility criteria
Introduction of all information sources (databases, contact with authors) and the date of the last search	9	Information sources
Introduction of the complete search strategy for at least one electronic database	10	Search strategy
		STUDY RECORDS
Description of the mechanism(s) used for data management	11-1	Data management
Statement of the study selection process (independent screening for meta-analysis)	11-2	Selection process
Description of the method of data extraction from reports and verification of information	11-3	Data collection process
List and definition of the variables for which data are sought	12	Data items
List and definition of all primary and secondary outcomes	13	Outcomes and prioritization
Description of the methods planned for assessing the risk of bias	14	Risk of bias in individual studies
		DATA
Description of the criteria covered for quantitative data synthesis	15-1	Synthesis of results
Description of the methods of data synthesis (including random or fixed models)	15-2	synthesis
Description of any additional proposed analyses (such as subgroup analysis)	15-3	Additional analyses
Specification of the assessment of the risk of bias in studies (such as publication bias)	16	Meta-bias
Description of how the strength of the body of evidence is assessed	17	Confidence in cumulative evidence

3.3. Stage Two: Delphi Technique

Following the identification of the antecedents and consequences of climate-smart agriculture development based on the systematic review of the literature, the validation of the items was carried out through expert opinion based on three Delphi rounds. The Delphi technique is a systematic approach for eliciting the opinions of a group of experts on a specific subject through a series of questionnaire rounds while maintaining the anonymity of respondents and providing feedback to panel members (Ahmadi et al., 2008). This technique is considered effective in cases where knowledge is incomplete or empirical evidence is scarce (Keeney et al., 2001).

The statistical population of this stage comprised experts and specialists in climate-smart agriculture in Iran in four groups: university professors (5 individuals) holding doctoral degrees in relevant fields, with at least three relevant scientific-research articles and experience in research-executive projects; senior experts of the Agricultural Jihad Organization (6 individuals) with at least ten years of work experience and participation in agricultural decision-making or planning at the regional level; experienced extension agents (9 individuals) with at least ten years of field experience, deep knowledge of farmers' problems, and a record of implementing relevant educational-extension programs; and regional managers (3 individuals), including directors-general and deputies of the Agricultural Jihad Organization and county managers with at least five years of managerial experience and familiarity with regional policies and executive challenges. Purposive sampling was conducted based on expertise, practical experience, systemic understanding of the problem, and diversity of viewpoints, and snowball sampling was used when necessary (Ahmadi et al., 2008). A sample size of 23 individuals was selected based on the recommendation of the Delphi literature for heterogeneous groups (20 to 30 individuals) (Keeney et al., 2001).

The Delphi process was conducted in three consecutive rounds. In the first round, a semi-structured questionnaire containing the initial list of antecedents and consequences along with an open-response section was provided to the 23 experts so that they could offer their opinions, corrections, and new proposed items. The open responses were coded using content analysis, similar items were merged, and duplicate or irrelevant items were removed; the output of this round was the transformation of the unstructured questionnaire into a structured questionnaire for the next round. In the second round, the structured questionnaire containing the finalized items was provided to the same group, and the importance of each item was rated on a five-point Likert scale. After data collection, consensus indicators including mean, median, standard deviation, and percentage of agreement were calculated, and items with a mean above 4 and an agreement coefficient above 70 percent were accepted for entry into the third round. In the third round, the statistical results of the second round were fed back to the experts, and they decided on the final retention or removal of each item in a yes/no format. The purpose of this round was to achieve final consensus and stabilize the key items, and items that obtained more than 70 percent "yes" agreement were accepted as final items. The Delphi process concluded after this round upon reaching consensus.

To measure the degree of agreement and concordance among panel members in each round, Kendall's coefficient of concordance was used, which is a nonparametric statistic for measuring the degree of agreement among raters and is used in Delphi studies to decide whether to terminate or continue the rounds (Schmidt, 1997). The value of this coefficient ranges from 0 to 1; a value of 1 indicates

complete agreement and a value of 0 indicates complete disagreement. The interpretation of the values of this coefficient is presented in Table 3.

Table 3. Interpretation of Kendall's Coefficient of Concordance Values

Interpretation of the Degree of Agreement	Kendall's Coefficient Value
Very weak	0.1
Weak	0.3
Moderate	0.5
Strong	0.7
Very strong	0.9

The objective of this study was to systematically identify the antecedents (driving and inhibiting factors) and consequences of climate-smart agriculture development in Iran. To achieve this objective, a three-stage process was implemented: a systematic review of the literature and extraction of the initial list, the Delphi technique for localization and validation, and final screening and compilation of the confirmed list. The results of the systematic review showed that attention to climate-smart agriculture has increased increasingly over the past two decades. At the international level, the trend of article publication from 2010 to 2026 has been upward and accelerating (Figure 1); in Iran as well, the trend of publications from 2011 to 2026 has been upward, but with a gentler slope, indicating the nascent nature of this concept in domestic literature and a greater focus on psychological and social acceptance aspects (Figure 2).

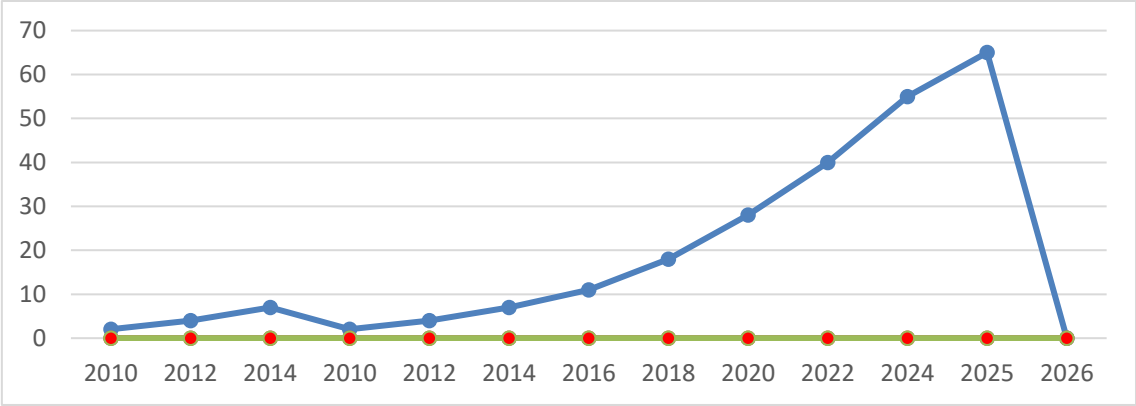

Figure 1. Trend of Changes in the Number of Climate-Smart Agriculture Studies outside Iran (2010–2026)

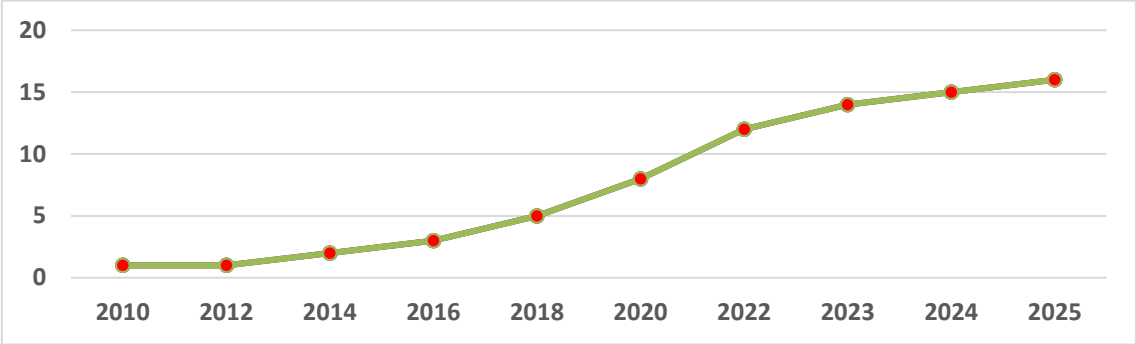

Figure 2. Trend of Changes in the Number of Climate-Smart Agriculture Studies inside Iran (2010–2026)

A comparative analysis of these two trends (Figure 3) reveals three key points. First, the difference in starting point and growth slope: at the international level, article publication began in 2010 with a gentle slope and accelerated after 2015, whereas in Iran the trend began in 2011 with a much gentler slope and has shown relative growth only since around 2019. Second, the existence of a time gap of approximately five to seven years in domestic literature relative to global literature, which is rooted in delayed translation and localization of concepts, differing policy priorities, scientific sanctions, and limited access to international databases. Third, the difference in the depth of studies: the absolute number of domestic studies (a maximum of 15 articles in 2025) is far smaller than that of international studies (more than 65 articles in 2025), and Iranian research has focused more on psychological and social acceptance aspects, whereas international literature covers a broader range of topics.

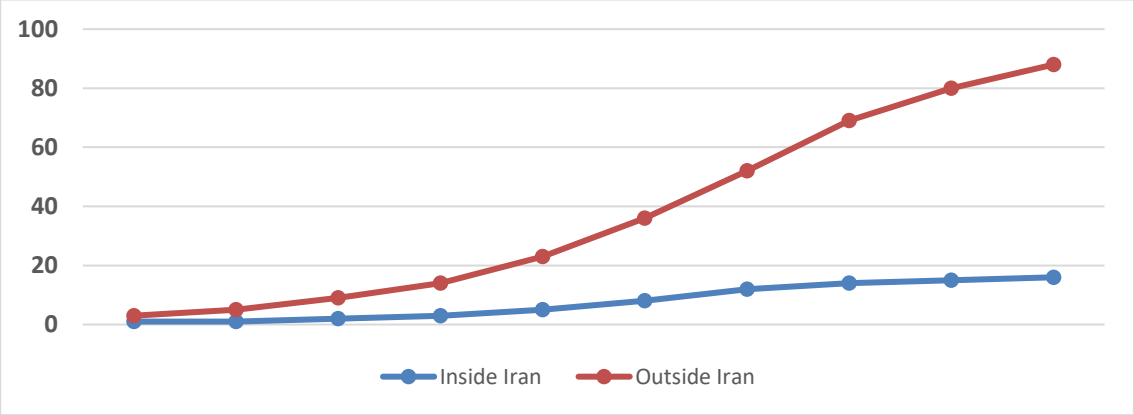

Figure 3. Comparison of the Trend of Changes in the Number of Climate-Smart Agriculture Studies inside Iran and outside Iran (2010–2026)

4.1. Distribution of Research Areas

The distribution of research areas of the analyzed articles is presented in Figure 4. The largest share of studies (28.3%) is devoted to the area of "adoption and factors influencing it," indicating a high concentration of research on identifying the factors that encourage or discourage farmers from adopting climate-smart agricultural technologies and practices. This is followed by the areas of "barriers and challenges" (18.2%) and "outcomes and effects" (16.2%). In contrast, the areas of "climate change and

vulnerability" (8.1%) and "psychology and farmers' behavior" (7.1%) have the smallest shares, while the remaining areas account for the rest of the distribution. This distribution indicates that the climate-smart agriculture literature is mainly focused on applied and policy aspects, while more fundamental aspects such as the psychological understanding of farmers' behavior and in-depth analysis of climate vulnerability have received less attention.

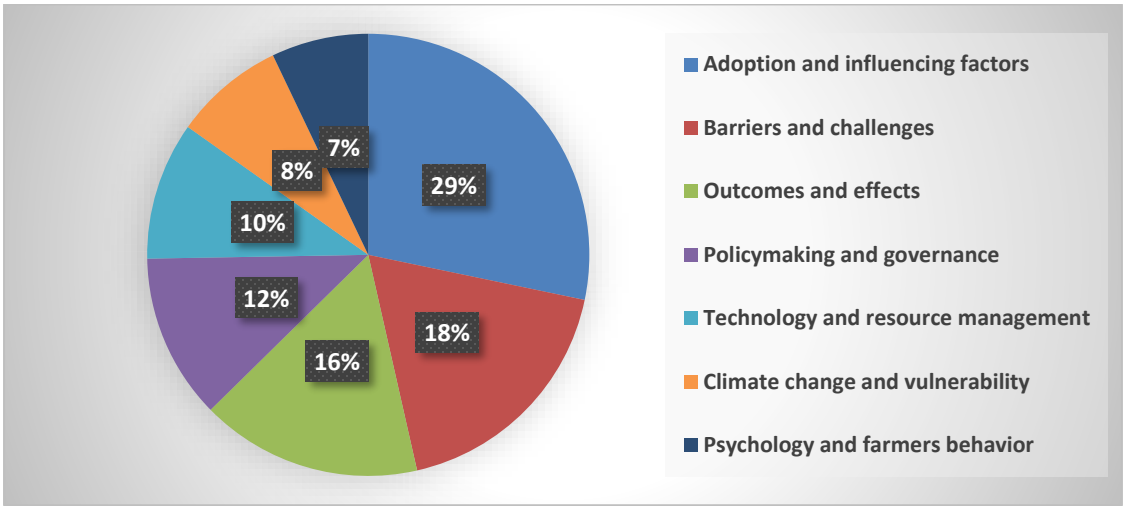

Figure 4. Distribution of Research Areas of the Analyzed Articles in the Field of Climate-Smart Agriculture

4.2. Identification of Antecedents (Driving Factors) of Climate-Smart Agriculture Development

4.3. Identification of Driving Factors

Table 4 presents the driving factors of climate-smart agriculture development based on the analysis of 99 articles (45 Persian and 54 English) across five dimensions: economic, institutional, technical and technological, socio-cultural, and environmental. In the economic dimension, access to credit and financial facilities (frequency 32) holds the highest position, indicating that securing financial resources is a fundamental precondition for adoption; this is followed by profitability and income increase (24) and market access (16). In the institutional dimension, extension and advisory services (38) are the most important driver of adoption in the entire table, followed by government policies and support (26) and land tenure security (18). In the technical and technological dimension, access to modern technologies (28), technical knowledge and skills (25), and communication infrastructure (14) are ranked in order of importance. In the socio-cultural dimension, social capital and networks (22), attitudes, beliefs, and individual awareness (20), and local community participation (18) were identified. In the environmental dimension, adaptation to climate change (18) and natural resource conservation (15) were also identified.

Table 4. Antecedents (Driving Factors) of Climate-Smart Agriculture Development

Overal l Rank	Rank within Comp onent	Frequen cy	English Researchers	Persian Researcher s	Constituent Variables	Antecedent (Driving Factor)	Row

						Economic Factors	1
2	1	32	Vasavi et al., 2025; Goren 2026; Ma & Rahut, 2024; Karimi & Ataei, 2024; Bakhshoudehnia et al., 2026 Ndabaningi et al., 2023	Karimi & Ataei, 2024; Qobadi Aliabadi et al., 2022; Mousaei, 2025; Hamdali et al. (2018)	Access to loans, microcredit, targeted subsidies	Access to credit and financial facilities	
5	2	24	Ma & Rahut, 2024; Saadu et al., 2024; Belay et al., 2023; Wollburg, et al., 2026	Jahangirpour & Zibaei, 2022; Bakhshoudehnia et al., 2024	Increased farm income, income diversification	Profitability and income increase	
12	3	16	Ma & Rahut, 2024; Goren 2026	Bakhshoudehnia et al., 2024; Ranjbar et al., 2025	Access to local and international markets	Market access	
9	3	14	Henry et al., 2024	Jahangirpour & Zibaei, 2022	Price of agricultural inputs, labor and energy costs	Production and input costs	
						Institutional Factors	2
1	1	38	Goren, 2022; Ma & Rahut, 2024; Vasavi et al., 2025; Wollburg, et al., 2026; Nshakira-Rukundo et al., 2026; Kakara, & Masambuka-Kanchewa 2025	Rafiei Sefiddashti et al., 2024; Karimi & Ataei, 2024; Khademi Noushabadi et al., 2022; Niroumand et al., 2020; Habibi Nokhandan & Masoumpour Amirabadi., 2025	Access to extension agents, practical training	Extension and advisory services	
3	2	26	FAO, 2025; Ma & Rahut, 2024;	Asadi et al., 2021;	Supportive laws,	Government policies and	

			Asseldonk et al., 2023; Schulze., 2024; Nelson et al., 2024;Olagunju et al., 2023;	Nowruzi & Hayati, 2015	government subsidies, development programs	support	
8	3	18	Ma & Rahut, 2024; Goren., 2026	Qobadi Aliabadi et al., 2022	Land ownership, exploitation rights	Land tenure security	
						Technical and Technological Factors	3
2	1	28	Emami et al., 2024;Vasavi et al., 2025; Li et al., 2024; Parra-Lopez et al., 2024	Abbasi Karvaneh et al., 2024; Jahangirpour & Zibaei, 2022; Esmailnejad, 2025; Bagherneja d et al., 2023	Pressurized irrigation, precision agriculture, sensors, climate information systems	Access to modern technologies	
4	2	25	Karimi & Ataei, 2026; Ma & Rahut, 2024; Ewulo et al., 2025; Valipour Parkouhi et al., 2026	Etemadi et al., 2022; Savari & Khaleghi, 2026; Abdollahza deh et al., 2014	Digital literacy, specialized training, ability to work with smart tools	Technical knowledge and skills	
14	3	14	FAO, 2025; Goren, 2026	Nowruzi & Hayati, 2015	High-speed internet, mobile network coverage, bandwidth in rural areas	Communicatio n infrastructure	
						Socio-cultural Factors	4
6	1	22	Ma & Rahut, 2024; Saadu et al., 2024; Ewulo et al., 2025 Xie, et al., 2024 Awuah et al., 2023	Savari & Khaleghi, 2026; Etemadi et al., 2022; Hosseinpou r et al. 2015	Membership in cooperatives, institutional trust	Social capital and networks	
8	2	18	Ma & Rahut, 2024; Wollburg, et al., 2026; Xie et al., 2024	Ranjbar et al., 2012; Jamshidi et al. 2025	articipation in decision-making, local organizations	Local community participation	

			Awuah et al., 2023; Vasavi et al., 2025				
7	3	20	Karimi & Ataei, 2026; Bakhshoudehnia et al., 2026; Ma & Rahut, 2024 van Valkengoed, & Steg., 2019	Etemadi et al., 2022; Bakhshoudehnia et al., 2024; Jamshidi et al., 2025	Belief in technology usefulness, willingness to accept risk, innovativeness (adoption of new ideas and technologies), environmental awareness	Attitudes, beliefs, and individual awareness	
						Environmental Factors	5
8	1	18	Ma & Rahut, 2024; Wollburg, et al., 2026 Kling 2024 et al., Othmani et al. 2023	Abbasi Karvaneh et al. 2024; Asadi et al., 2021	Crop diversification, resistant varieties	Adaptation to climate change	
12	2	15	Ma & Rahut, 2024; Henry et al., 2024	Jahangirpour & Zibaei, 2022; Marzban et al., 2020; Mohammadi et al., 2018; Salehi et al., 2010; Fallahi & Riahi, 2025	Water and soil management, carbon sequestration	Natural resource conservation	

4.4. Identification of Barriers to Climate-Smart Agriculture Development

Table 5 presents the barriers to climate-smart agriculture development across three levels of intervention. At the first level (macro-structural barriers), high implementation costs (frequency 28) are the most important barrier in the entire table, indicating that the initial financial burden of investment is the main bottleneck facing farmers; this is followed by the lack of digital infrastructure (23), the absence of supportive policies (20), and weak intersectoral coordination (12). At the second level (institutional-extension barriers), weak extension services (25) are the most important barrier at this level and the second overall barrier in the table, followed by the lack of technical knowledge and skills (20) and the immaturity of technologies (11). At the third level (behavioral-cultural barriers), resistance to change (18) is the most important barrier at this level and the fourth overall barrier in the table, followed by distrust of technology (14) and gender inequality (8).

Table 5. Barriers to Climate-Smart Agriculture Development

Overall Rank	Rank within Component	Frequency	English Researchers	Persian Researchers	Constituent Variables	Component (Barrier)	Level of Intervention	Row
1	1	28	Goren, 2026; Vasavi et al., 2025; Ewulo et al., 2025 Kelly et al., 2023	Karimi & Ataei, 2024; Abbasi Karvaneh et al., 2024; Valipour Parkouhi et al., 2026; Razzaqi Bourkhani et al., 2018	Initial technology cost, capital-intensive nature	High implementation costs	Structural barriers (macro)	1
3	2	20	Ma & Rahut, 2024; Asseldonk et al., 2023	Asadi et al., 2021; Bagheri, 2021	Lack of supportive laws, lack of priority in upstream documents	Absence of supportive policies		
2	3	23	Goren, 2026; Ma & Rahut, 2024	Nowruzi & Hayati 2015; Karimi & Ataei, 2024	Weak internet, lack of access to technology in rural areas	Lack of digital infrastructure		
8	4	12	Karimi & Ataei, 2024 Abate et al., 2023	Karimi & Ataei, 2024; Louimi & Khosravipour, 2024	Institutional inconsistency, parallel work	Weak intersectoral coordination		
2	1	25	Goren(2026; Ma & Rahut, 2024; Ewulo et al., 2025	Rafiei Sefiddashti et al., 2024; Karimi & Ataei, 2024	Shortage of extension agents, inadequate practical training	Weak extension services	Institutional-extension barriers (meso)	2
3	2	20	Karimi & Ataei, 2026; Ewulo et al., 2025	Etemadi et al., 2022; Valipour Parkouhi et al., 2026	Digital illiteracy, lack of technical training	Lack of technical knowledge and skills		
9	3	11	Emami et al., 2024; Valipour Parkouhi et al., 2026	Abbasi Karvaneh et al., 2024; Rahimi, 2022	Absence of implementation guidelines, immature technologies	Immaturity of technologies		
4	1	18	Karimi &	Savari &	Fear of the	Resistance	Behaviora	3

			Ataei, 2026; Ma & Rahut, 2024 Moser et al., 2026	Khaleghi, 2026; Etemadi et al., 2022	unknown, habit of traditional methods	to change	l-cultural barriers (micro)
6	2	14	Karimi & Ataei, 2026; Ewulo et al., 2025	Etemadi et al., 2022; Qanbari et al., 2012	Pessimism toward technology, fear of workforce replacement	Distrust of technology	
11	3	8	Goren, 2026; Evertsen, 2022	Qobadi Aliabadi et al., 2022; Azari & Chamani, 2023	Limited access of women to resources and training	Gender inequality	

4.5. Identification of Consequences (Economic, Social, and Environmental Outcomes) of Climate-Smart Agriculture Development

Table 6 presents the consequences of climate-smart agriculture development in three dimensions: economic, social, and environmental. In the economic dimension, increased productivity and crop yield (frequency 30) are the most important consequence and rank first in the entire table, indicating that this approach is viewed primarily as a strategy for increasing production per unit area; increased income and profitability (26), livelihood diversification (18), employment creation (16), poverty reduction (15), and reduced production costs (14) follow in subsequent ranks. In the social dimension, improved food security and dietary diversity (22) are the most important consequence and rank third in the entire table; reduced rural migration (20), increased resilience to climate shocks (18), strengthened social capital (14), enhanced technical knowledge and skills (13), and empowerment of women and vulnerable groups (12) follow. In the environmental dimension, reduced greenhouse gas emissions (24) are the most important consequence and rank second in the entire table, indicating that this approach functions as a "win-win" strategy; improved water productivity (18), soil carbon sequestration (16), improved soil quality and health (14), reduced pressure on natural resources (12), and biodiversity conservation (10) follow in subsequent ranks.

Table 6. Consequences (Economic, Social, and Environmental Outcomes) of Climate-Smart Agriculture Development

Overall Rank	Rank within Component	Frequency	English Researchers	Persian Researchers	Constituent Variables	Component (Outcome)	Dimension	Row
1	1	30	Ma & Rahut, 2024; Saadu et al., 2024; Simutowe	Jahangirpour & Zibaei, 2022; Bakhshoudeh nia et al.,	Increased yield per hectare, improved production efficiency	Increased productivity and crop yield	Economic	**1**

			et al., 2025	2024				
2	2	26	Belay et al., 2024; Mnukwa et al., 2025; Wollburg, et al., 2026	Jahangirpour & Zibaei, 2022; Qobadi Aliabadi et al., 2022	Increased net income, improved household livelihood	Increased income and farm profitability		
9	3	14	Henry et al., 2024	Jahangirpour & Zibaei, 2022	Optimization of water, energy, and input consumption	Reduced production costs		
5	4	18	Ma & Rahut, 2024; Mnukwa et al., 2025	Bakhshoudehnia et al., 2024	Creation of non-agricultural jobs, promotion of agricultural tourism	Livelihood diversification and income sources		
7	5	16	Mnukwa et al., 2025; Wollburg, et al., 2026	Qobadi Aliabadi et al., 2022	Direct and indirect employment in the value chain	Employment creation (especially for women and youth)		
8	6	15	Belay et al., 2024; Simutowe et al., 2025	Asadi et al., 2021; Sayyidi Mohammadi et al. 2021; Baghernejad et al. 2022	Increased purchasing power, reduced economic vulnerability	Poverty reduction and improved household welfare		
3	1	22	Belay et al., 2024; Mnukwa et al., 2025; Wollburg, et al., 2026 van Gameren et al 2024 Bene et al., 2023	Asadi et al., 2021	Access to sufficient and nutritious food, dietary diversity	Improved food security and dietary diversity	Social	**2**

4	2	20	Ma & Rahut, 2024; Mnukwa et al., 2025	Qobadi Aliabadi et al., 2022	Creation of incentives to stay, reverse migration	Reduced rural migration and desire to remain		
5	3	18	Ma & Rahut, 2024; Karimi & Ataei, 2024	Asadi et al., 2021; Savari & Khaleghi, 2026; Ranjbar et al., 2012	Resistance to drought, floods, and climatic fluctuations	Increased resilience to climate shocks		
11	4	12	Mnukwa et al., 2025	Qobadi Aliabadi et al., 2022	Increased women's participation, access to resources	Empowerment of women and vulnerable groups		
9	5	14	Ma & Rahut, 2024	Savari & Khaleghi, 2026; Ranjbar et al., 2021; Bonyasadi & Shafi Moradi 2026	Increased cooperation, strengthening of organizations and cooperatives	Strengthened social capital and local participation		
10	6	13	Karimi & Ataei, 2026; Ewulo et al., 2025	Etemadi et al., 2022	Increased digital literacy, technical skills	Enhanced technical knowledge and skills of farmers		
2	1	24	Ma & Rahut, 2024; Henry et al., 2024	Jahangirpour & Zibaei, 2021	Reduction of methane, nitrous oxide, and CO_2	Reduced greenhouse gas emissions	Environmental	**3**
7	2	16	Henry et al., 2024; Wollburg, et al., 2026 Alekseev & Abakumov 2024	Marzban et al., 2020	Increased soil organic matter, carbon storage	Soil carbon sequestration		
5	3	18	Emami et al 2024	Jahangirpour & Zibaei, 2021; Abbasi Karvaneh et	Reduced water consumption per unit	Improved water productivity		

				al. 2024	of product	
9	4	14	Henry et al., 2024	Marzban et al., 2020	Reduced erosion, increased fertility	Improved soil quality and health
13	5	10	Wollburg, et al., 2026 Daum et al., 2023	Marzban et al., 2020; Ghaffari Farsani & Malekian 2025	Species conservation, improved pollination, pest control	Biodiversity conservation and ecosystem services
11	6	12	Emami et al 2024	Abbasi Karvaneh et al. 2024; Asadi et al., 2021	Reduced groundwater extraction, forest conservation	Reduced pressure on natural resources

4.6.Delphi Findings

Following the extraction of the initial list of antecedents and consequences from the systematic review (44 items comprising 27 antecedents and 17 consequences), the second stage was implemented with the aim of contextualizing, validating, and finalizing this list using the Delphi technique. The Delphi process was conducted in three consecutive rounds, and in each round, consensus indicators (mean, median, standard deviation, and percentage of agreement) and Kendall's coefficient of concordance were calculated and analyzed.

4.6.1. First Round

In this round, a semi-structured questionnaire containing the 44 initial items (44 items comprising 27 antecedents and 17 consequences) was provided to the 23 experts so that they could confirm, modify, or complete the initial list. For each item, three options were considered: "appropriate / requires modification / inappropriate," and at the end of the questionnaire, an open-response section was designed for proposing new items. The initial list of driving factors was organized within five dimensions economic, institutional, technical and technological, socio-cultural, and environmental—and the initial list of barriers was organized across three levels—structural, institutional-extension, and behavioral-cultural (Table 7).

Table 7. Initial List of Antecedents (Driving Factors and Barriers) of Climate-Smart Agriculture Development Presented to Experts in the First Delphi Round

Dimension	Barriers	Code	Dimension	Driving Factors	Code
Structural	High implementation costs	B1	Economic	Access to credit and financial facilities	P1
Structural	Absence of supportive policies	B2	Economic	Profitability and income increase	P2

Structural	Lack of digital infrastructure	B3	Economic	Market access	P3
Structural	Weak intersectoral coordination	B4	Economic	Production and input costs	P4
Structural	Sanctions and technology restrictions	B5	Economic	Agricultural insurance and guarantee fund	P5
Structural	Economic fluctuations and inflation	B6	Economic	Livelihood diversification	P6
Institutional-extension	Weak extension services	B7	Institutional	Extension and advisory services	P7
Institutional-extension	Lack of technical knowledge and skills	B8	Institutional	Government policies and support	P8
Institutional-extension	Immaturity of technologies	B9	Institutional	Land tenure security	P9
Institutional-extension	Weak insurance and risk management system	B10	Institutional	Intersectoral coordination of institutions	P10
Institutional-extension	Insufficient research funding	B11	Institutional	Development of organizations and cooperatives	P11
Institutional-extension	Weak monitoring and evaluation mechanism	B12	Technical	Access to modern technologies	P12
Behavioral-cultural	Resistance to change	B13	Technical	Access to climate data	P13
Behavioral-cultural	Distrust of technology	B14	Technical	Technical knowledge and skills	P14
Behavioral-cultural	Gender inequality	B15	Technical	Communication infrastructure	P15
Behavioral-cultural	Farmers' risk aversion	B16	Technical	Water storage technologies	P16
Behavioral-cultural	Lack of entrepreneurial spirit	B17	Socio-cultural	Social capital and networks	P17
Structural	High implementation costs	B1	Socio-cultural	Local community participation	P18
Structural	Absence of supportive policies	B2	Socio-cultural	Attitudes, beliefs, and individual awareness	P19
Structural	Lack of digital infrastructure	B3	Socio-cultural	Women's empowerment	P20
Structural	Weak intersectoral coordination	B4	Socio-cultural	Education and capacity-building	P21
Structural	Sanctions and technology restrictions	B5	Environmental	Adaptation to climate change	P22
Structural	Economic fluctuations and inflation	B6	Environmental	Natural resource conservation	P23
Institutional-extension	Weak extension services	B7	Environmental	Sustainable water and soil management	P24
Institutional-extension	Lack of technical knowledge and skills	B8	Environmental	Biodiversity conservation	P25
Institutional-extension	Immaturity of technologies	B9	Environmental	Environmental impact monitoring	P26
Institutional-extension	Weak insurance and risk management system	B10	Environmental	Low-carbon agricultural development	P27

Of the 23 questionnaires distributed in the first round, all were completed and returned. Content analysis of the responses in the open-response section led to the identification of 28 new items that at least three experts had mentioned; these items comprised 14 new driving factors (P28 to P41) and 14 new barriers (B18 to B31). In addition, 5 items were identified as requiring verbal modification, and 3 overlapping items were marked for merging in the second round. Ultimately, a list of 72 items (41 driving factors and 31 barriers) was compiled as input for the second round (Table 8).

Table 8. New Items Proposed by Experts in the First Round

Number of Experts	Dimension/Level	New Item	Code
5	Technical	Access to sustainable and renewable energy	P28
4	Economic	Development of processing and value-added industries for agricultural products	P29
4	Technical	Access to satellite data and remote sensing	P30
4	Environmental	Development of medicinal and low-water-demand plant cultivation	P31
3	Technical	Revitalization of qanats and traditional water infrastructure	P32
3	Economic	Border cooperation and exports	P33
3	Economic-Social	Development of agricultural tourism and agritourism	P34
4	Technical	Development of greenhouse cultivation	P35
4	Economic	Increasing farmers' financial literacy	P36
3	Socio-cultural	Cultural development and increasing public awareness of digital technologies	P37
3	Institutional	Establishment of digital technology units in responsible organizations	P38
3	Institutional	Establishment of a digital technology management and leadership headquarters in the province	P39
3	Socio-cultural	Focus on rural youth	P40
4	Economic	Provision of bank capital at appropriate interest rates	P41
4	Structural	Labor migration and reduction of the active rural population	B18
3	Structural	Change in agricultural land use	B19
3	Structural	Weak market and value chain infrastructure	B20
3	Structural	Seasonal labor migration	B21
4	Structural	Smuggling of livestock, inputs, and products	B22
4	Institutional-extension	Local conflicts over water allocation	B23
3	Structural	Deterioration of traditional water infrastructure	B24
3	Structural	Insecurity of investment in border areas	B25
3	Structural	Land use change to construction	B26
3	Structural	Weak transportation and cold chain infrastructure	B27
4	Structural	International sanctions and restrictions on access to technology	B28
4	Behavioral-cultural	Aging and illiteracy of farmers	B29
4	Structural	Fragmentation and smallholding of agricultural land	B30
4	Institutional-extension	Shortage of digital technology experts and specialists	B31

Kendall's coefficient of concordance for the first round was obtained as $W = 0.312$, which falls at the "weak agreement" level and indicates that the experts' views were diverse and scattered at the

beginning of the process. The chi-square test with a degree of freedom of df = 71 and a value of χ^2 = 494.2 was significant at the $p < 0.001$ level, which justifies the necessity of conducting subsequent rounds.

In the second round, a structured questionnaire containing 72 items (41 driving factors and 31 barriers) was provided to the same 23 experts, and they were asked to specify the importance of each item on a five-point Likert scale. The acceptance criterion for each item was obtaining a mean above 4 and an agreement percentage above 70 percent (Keeney et al., 2001). Of the 72 items, 11 items with a mean below 4 or an agreement percentage below 70 percent were removed, comprising P4 (production costs), P15 (communication infrastructure), P26 (environmental monitoring), P38 (establishing digital technology units in organizations), B5 (sanctions and technology restrictions), B6 (economic fluctuations and inflation), B15 (gender inequality), B19 (agricultural land use change), B20 (weak market infrastructure), B25 (insecurity of investment in border areas), and B28 (international sanctions), and 61 items (37 driving factors + 24 barriers) were accepted for entry into the third round (Tables 9 and 10).

Table 9. Results of the Second Delphi Round (Driving Factors)

Result	Agreement Percentage	Standard Deviation	Median	Mean	Item	Code
Accepted	91	0.800	5	4.61	Access to credit and financial facilities	P1
Accepted	87	0.917	5	4.43	Profitability and income increase	P2
Accepted	78	0.960	4	4.22	Market access	P3
Rejected	61	1.112	3	3.65	Production and input costs	P4
Accepted	83	0.947	4	4.26	Agricultural insurance and guarantee fund	P5
Accepted	78	0.982	5	4.13	Livelihood diversification	P6
Accepted	96	0.765	5	4.70	Extension and advisory services	P7
Accepted	91	0.822	5	4.48	Government policies and support	P8
Accepted	74	1.000	4	4.05	Land tenure security	P9
Accepted	78	0.995	4	4.10	Intersectoral coordination of institutions	P10
Accepted	78	0.957	4	4.18	Development of organizations and cooperatives	P11
Accepted	91	0.842	5	4.52	Access to modern technologies	P12
Accepted	91	0.854	5	4.48	Access to climate data	P13
Accepted	87	0.906	4	4.35	Technical knowledge and skills	P14
Rejected	65	1.051	4	3.80	Communication infrastructure	P15
Accepted	83	0.937	4	4.22	Water storage technologies	P16
Accepted	83	0.931	4	4.30	Social capital and networks	P17
Accepted	74	1.000	4	4.12	Local community participation	P18
Accepted	83	0.950	4	4.26	Attitudes, beliefs, and individual awareness	P19
Accepted	74	1.015	4	4.05	Women's empowerment	P20
Accepted	78	0.984	4	4.10	Education and capacity-building	P21
Accepted	87	0.895	5	4.39	Adaptation to climate change	P22
Accepted	83	0.947	4	4.20	Natural resource conservation	P23
Accepted	74	0.970	4	4.05	Sustainable water and soil management	P24
Accepted	74	1.027	4	4.05	Biodiversity conservation	P25

Rejected	61	1.085	3	3.70	Environmental impact monitoring	P26
Accepted	74	0.978	4	4.05	Low-carbon agricultural development	P27
Accepted	78	0.960	4	4.13	Access to sustainable and renewable energy	P28
Accepted	87	0.900	4	4.35	Development of processing and value-added industries	P29
Accepted	83	0.935	4	4.22	Access to satellite data	P30
Accepted	78	0.975	4	4.18	Development of medicinal plant cultivation	P31
Accepted	78	0.981	4	4.10	Revitalization of qanats and traditional infrastructure	P32
Accepted	74	1.000	4	4.05	Border cooperation and exports	P33
Accepted	78	0.972	4	4.13	Development of agricultural tourism	P34
Accepted	83	0.920	4	4.26	Development of greenhouse cultivation	P35
Accepted	74	0.994	4	4.05	Increasing farmers' financial literacy	P36
Accepted	78	0.982	4	4.10	Cultural development and public awareness	P37
Rejected	65	1.021	4	3.95	Establishment of digital technology units in organizations	P38
Accepted	74	1.000	4	4.05	Establishment of a digital technology management headquarters	P39
Accepted	78	0.974	4	4.13	Focus on rural youth	P40
Accepted	74	1.012	4	4.00	Provision of bank capital at appropriate interest rates	P41

Table 10. Results of the Second Delphi Round (Barriers)

Result	Agreement Percentage	Standard Deviation	Median	Mean	Item	Code
Accepted	94	0.792	5	4.65	High implementation costs	B1
Accepted	87	0.917	4	4.30	Absence of supportive policies	B2
Accepted	91	0.865	5	4.43	Lack of digital infrastructure	B3
Accepted	78	0.994	4	4.10	Weak intersectoral coordination	B4
Rejected	65	1.022	4	3.95	Sanctions and technology restrictions	B5
Rejected	61	1.045	4	3.85	Economic fluctuations and inflation	B6
Accepted	91	0.812	5	4.57	Weak extension services	B7
Accepted	87	0.900		4.35	Lack of technical knowledge and skills	B8
Accepted	74	1.000	4	4.05	Immaturity of technologies	B9
Accepted	78	0.965	4	4.13	Weak insurance and risk management system	B10
Accepted	74	1.012	4	4.05	Insufficient research funding	B11
Accepted	74	1.000	4	4.00	Weak monitoring and evaluation mechanism	B12
Accepted	83	0.960	4	4.22	Resistance to change	B13
Accepted	74	1.037	4	4.05	Distrust of technology	B14

Rejected	65	1.084	4	3.80	Gender inequality	B15
Accepted	74	1.000	4	4.05	Farmers' risk aversion	B16
Accepted	74	1.025	4	4.00	Lack of entrepreneurial spirit	B17
Accepted	78	0.980	4	4.10	Labor migration	B18
Rejected	61	1.120	4	3.75	Agricultural land use change	B19
Rejected	65	1.057	4	3.85	Weak market infrastructure	B20
Accepted	78	0.957	4	4.18	Seasonal labor migration	B21
Accepted	83	0.924	4	4.26	Smuggling of livestock, inputs, and products	B22
Accepted	87	0.917	4	4.30	Local conflicts over water	B23
Accepted	78	0.965	4	4.13	Deterioration of traditional water infrastructure	B24
Rejected	65	1.040	4	3.90	Insecurity of investment in border areas	B25
Accepted	74	0.990	4	4.05	Land use change to construction	B26
Accepted	74	1.017	4	4.00	Weak transportation infrastructure	B27
Rejected	65	1.037	4	3.95	International sanctions	B28
Accepted	87	0.917	4	4.30	Aging and illiteracy of farmers	B29
Accepted	78	0.984	4	4.10	Fragmentation of land	B30
Accepted	83	0.945	4	4.22	Shortage of specialized experts	B31

Kendall's coefficient of concordance for the second round was obtained as $W = 0.548$, which falls at the "moderate agreement" level and indicates a relative convergence of the experts' views compared with the first round. The chi-square test with a degree of freedom of $df = 60$ and a value of $\chi^2 = 735.4$ was significant at the $p < 0.001$ level, and the increase compared with the first round confirmed the experts' movement toward consensus.

In the third round, a yes/no questionnaire containing 61 items (37 driving factors and 24 barriers) was provided to the experts, and the statistical results of the second round were presented as feedback. The acceptance criterion in this round was obtaining more than 70 percent "yes" votes for the retention of each item (Schmidt, 1997). None of the items received fewer than 70 percent of "yes" votes, and all 61 items were retained, indicating strong and stable consensus among the experts on the importance of all remaining items (Tables 11 and 12).

Table 11. Results of the Third Delphi Round for Driving Factors

Result	Percentage (Yes)	Item	Code
Retained	96	Access to credit and financial facilities	P1
Retained	91	Profitability and income increase	P2
Retained	83	Market access	P3
Retained	83	Agricultural insurance and guarantee fund	P5
Retained	78	Livelihood diversification	P6
Retained	96	Extension and advisory services	P7
Retained	91	Government policies and support	P8
Retained	74	Land tenure security	P9
Retained	78	Intersectoral coordination of institutions	P10
Retained	78	Development of organizations and cooperatives	P11

Retained	91	Access to modern technologies	P12
Retained	91	Access to climate data	P13
Retained	87	Technical knowledge and skills	P14
Retained	83	Water storage technologies	P16
Retained	83	Social capital and networks	P17
Retained	74	Local community participation	P18
Retained	83	Attitudes, beliefs, and individual awareness	P19
Retained	74	Women's empowerment	P20
Retained	78	Education and capacity-building	P21
Retained	87	Adaptation to climate change	P22
Retained	83	Natural resource conservation	P23
Retained	74	Sustainable water and soil management	P24
Retained	74	Biodiversity conservation	P25
Retained	74	Low-carbon agricultural development	P27
Retained	78	Access to sustainable and renewable energy	P28
Retained	87	Development of processing and value-added industries	P29
Retained	83	Access to satellite data	P30
Retained	78	Development of medicinal plant cultivation	P31
Retained	78	Revitalization of qanats and traditional infrastructure	P32
Retained	74	Border cooperation and exports	P33
Retained	78	Development of agricultural tourism	P34
Retained	83	Development of greenhouse cultivation	P35
Retained	74	Increasing farmers' financial literacy	P36
Retained	78	Cultural development and public awareness	P37
Retained	74	Establishment of a digital technology management headquarters	P39
Retained	78	Focus on rural youth	P40
Retained	74	Provision of bank capital at appropriate interest rates	P41

Table 12. Results of the Third Delphi Round for Barriers

Result	Percentage (Yes)	Item	Code
Retained	96	High implementation costs	B1
Retained	87	Absence of supportive policies	B2
Retained	91	Lack of digital infrastructure	B3
Retained	78	Weak intersectoral coordination	B4
Retained	91	Weak extension services	B7
Retained	87	Lack of technical knowledge and skills	B8
Retained	74	Immaturity of technologies	B9

Retained	78	Weak insurance and risk management system	B10
Retained	74	Insufficient research funding	B11
Retained	74	Weak monitoring and evaluation mechanism	B12
Retained	83	Resistance to change	B13
Retained	74	Distrust of technology	B14
Retained	74	Farmers' risk aversion	B16
Retained	74	Lack of entrepreneurial spirit	B17
Retained	78	Labor migration	B18
Retained	78	Seasonal labor migration	B21
Retained	83	Smuggling of livestock, inputs, and products	B22
Retained	87	Local conflicts over water	B23
Retained	78	Deterioration of traditional water infrastructure	B24
Retained	74	Land use change to construction	B26
Retained	74	Weak transportation infrastructure	B27
Retained	78	Aging and illiteracy of farmers	B29
Retained	78	Fragmentation of land	B30
Retained	83	Shortage of specialized experts	B31

In the third round, Kendall's coefficient of concordance was obtained as $W = 0.721$, which falls at the "strong agreement" level and indicates strong consensus among the panel members. The chi-square test with a degree of freedom of $df = 60$ and a value of $\chi^2 = 967.5$ was significant at the $p < 0.001$ level, which confirms the statistical validity of the consensus and justifies the termination of the Delphi process.

The upward trend of Kendall's coefficient of concordance from 0.312 in the first round to 0.548 in the second round and then to 0.721 in the third round indicates gradual convergence and the achievement of strong consensus (Table 12). The value of χ^2 was significant at the $p < 0.001$ level in all three rounds, which confirms the statistical validity of the consensus (Table 13).

Table 13. Trend of Kendall's Coefficient of Concordance Across the Three Delphi Rounds

Interpretation	Significance Level	df	$\chi 2$		Number of Items	Round
Weak agreement	p<0.001	61	425.6	0.312	62	First
Moderate agreement	p<0.001	52	0.639	0.548	53	Second
Strong agreement	p<0.001	52	840.7	0.721	53	Third

5. Discussion

The development of climate-smart agriculture is the product of the intertwining of a set of antecedents and barriers operating at different levels, and no single factor alone can explain its adoption and expansion in drought-prone agricultural systems. The most prominent finding is that extension and advisory services rank first among the driving factors, while their weakness is the second overall barrier; this overlap indicates that the extension system can be either the main key to transition or, if weak, the main bottleneck. This result is consistent with the findings of Nshakira-Rukundo et al. (2026) and Mnukwa et al. (2025), who identified education, access to information, and extension services as the strongest predictors of adoption and attributed a severalfold increase in adoption to extension services, and it also aligns with the domestic results of Rafiei Sefiddashti et al. (2024) and Karimi and Ataei (2024) regarding the role of systemic factors and the capacity-building of extension experts. Accordingly, the first policy implication is that any transition strategy must begin with a redesign of the extension system toward practical, farm-based, and participatory advisory services, including the training of specialized climate-smart extension agents and the establishment of technical advisory units at the regional level; without such a redesign, even well-designed financial and technological packages are unlikely to reach farmers in a usable form.

At the next level, the dominance of financial and structural barriers is evident: high implementation costs were identified as the most important overall barrier, and access to credit and financial facilities as the second overall driving factor. This symmetry indicates that the main problem of farmers is not unawareness of the benefits of climate-smart agriculture but rather financial inability to enter it. This result is consistent with the findings of Vasavi et al. (2025), Billah et al. (2025), and Senyolo et al. (2018) regarding high initial costs and limited access to credit, and it is aligned with the results of Khaledi et al. (2016) and Amiri and Mirkzadeh (2022), who identified lack of credit and lack of financial support as major barriers to adaptation and technology adoption in Iranian agricultural regions. The corresponding policy implication is the design of targeted financial instruments, including low-interest credit lines dedicated to climate-smart investments, guarantee funds for smallholders, climate index-based insurance to reduce production risk, and time-bound subsidies for initial capital costs; these instruments should be bundled with extension services so that financial access and technical guidance reinforce each other rather than operate in isolation.

The importance of institutional and policy factors alongside technical factors are also evident: government policies and support were the third driving factor, the absence of supportive policies was the third overall barrier, and the lack of digital infrastructure was identified as the second overall barrier. This result is aligned with the emphasis of Vecchio et al. (2026) on the "information-institution-livelihood" framework and with the finding of Asseldonk et al. (2023) regarding the impact of policy instruments on adoption, and it indicates that without an enabling institutional environment and digital infrastructure, even effective technologies will fail at the scaling stage (Keshavarz & Sharafi, 2023). The practical implication is twofold: first, climate-smart agriculture must be embedded in national and regional development plans and budget allocations, with an intersectoral coordination body linking agriculture, water, and environment authorities; second, rural digital infrastructure, early drought warning systems, and farmers' access to satellite and meteorological data should be treated as prerequisites of technology adoption rather than as complementaryadd-ons.

Behavioral-cultural factors also hold an important position: resistance to change was the fourth overall barrier, and attitudes, beliefs, and individual awareness were among the important driving factors. This result is consistent with the findings of Savari and Khaleghi (2026) regarding the role of social norms and habits, Khademi Noushabadi et al. (2022) regarding personal norms and perceived behavioral control, and Qobadi Aliabadi et al. (2022) regarding the diversity of risk perception among farmers, and it confirms that the attitude-behavior gap remains one of the main challenges (Azadi et al., 2019; Yazdanpanah et al., 2014). It is noteworthy that gender inequality was removed in the second Delphi round; this difference from the international literature (Mnukwa et al., 2025; Evertsen, 2022) may be due to contextual differences, the composition of the expert panel, or the prioritization of local experts, and it warrants further investigation. The corresponding recommendation is to complement technical and financial measures with trust-building and social learning mechanisms, including demonstration farms led by progressive farmers, farmer field schools, strengthened cooperatives and local organizations, and the involvement of local communities in decision-making; such measures can reduce resistance to change and convert awareness into sustained behavioral change.

Finally, the "win-win" nature of climate-smart agriculture was confirmed: increased productivity and crop yield were identified as the most important economic consequence, improved food security as the most important social consequence, and reduced greenhouse gas emissions as the most important environmental consequence. This result is consistent with the findings of Belay et al. (2024), Simutowe et al. (2025), and Benson et al. (2023) and indicates that economic, social, and environmental objectives can be achieved simultaneously in drought-prone agricultural systems. Moreover, the finding of Asadi et al. (2021) that "increased adaptation" is the most influential component and "income sustainability" the most influenced component is consistent with the present results. This triple dividend strengthens the case for integrating climate-smart agriculture into national food security and climate strategies, and it suggests that livelihood diversification through processing industries, cultivation of medicinal and low-water-demand plants, agricultural tourism, and non-agricultural activities should be pursued alongside productivity-enhancing measures to reduce the vulnerability of rural households.

Taken together, these findings indicate that the transition to climate-smart agriculture cannot be achieved through isolated interventions. It requires an integrated policy package in which extension capacity, targeted financing, institutional reform, digital infrastructure, and behavioral change are designed and implemented as mutually reinforcing components. Such a package is not specific to a single region; it offers a transferable template for other drought-prone agricultural systems in developing countries that face comparable climatic, institutional, and financial constraints.

6. Conclusion

Conclusion

The present study, by systematically synthesizing 99 studies and validating the findings through the opinions of 23 experts in Iran, achieved a comprehensive framework of the antecedents and consequences of climate-smart agriculture development. The main conclusion is that the development of this approach is more an institutional, financial, and behavioral issue than a technical one. Extension services, access to credit, supportive policies, digital infrastructure, and farmers' attitudes are the most determining factors, and without simultaneous attention to them, the introduction of technology alone will not be effective. The Delphi process, by reaching Kendall's coefficient of concordance of 0.721, showed that the experts have strong consensus on the priority of these factors, and the 61 finalized items can serve as a basis for action. It was also confirmed that the development of climate-smart agriculture can simultaneously improve productivity and income, food security and social resilience, and environmental sustainability. The findings showed that structural and financial barriers, particularly high implementation costs and the lack of digital infrastructure, are still the main bottlenecks facing farmers, and on the other hand, weak extension services and lack of technical knowledge and skills deepen the gap between policy and practice. From a behavioral perspective, resistance to change and distrust of technology indicate that the adoption of this approach cannot be achieved through financial incentives alone and requires trust-building, participation, and continuous education. Overall, the study concludes that climate-smart agriculture is not a single technological package to be transferred, but a systemic transition that depends on the simultaneous alignment of institutional capacity, financial instruments, digital infrastructure, and farmers' behavior; where these elements are aligned, the triple dividend of productivity, resilience, and environmental sustainability becomes achievable, and where they are not, even well-designed technologies remain underused. The framework developed here therefore provides an evidence-based and expert-validated basis for understanding why climate-smart agriculture succeeds or fails in drought-prone agricultural systems, and it offers a transferable reference for analyzing similar transitions in other developing countries facing comparable climatic and institutional constraints.

7. Research Implications

7.1. Theoretical Implications

The present study contributes to the theoretical literature on climate-smart agriculture by moving beyond fragmented, case-specific accounts and offering an integrated framework that links antecedents and consequences within a single analytical structure. Theoretically, it reframes climate-smart agriculture not as a fixed bundle of technologies but as a systemic transition shaped by the interaction of institutional capacity, financial instruments, digital infrastructure, and farmers' behavior, thereby extending the technology-adoption literature toward a more systemic and context-sensitive perspective. It also advances the "information-institution-livelihood" debate by demonstrating that information and technology alone do not drive adoption unless they are mediated by credible extension systems, supportive policies, and secure livelihoods, and it enriches the attitude-behavior literature by showing that resistance to change and distrust of technology remain central theoretical obstacles even when financial and technical conditions are favorable. Finally, the study provides a methodological

contribution by combining meta-synthesis with Delphi validation, illustrating how scattered qualitative and quantitative evidence can be systematically synthesized and then contextualized through expert judgment, a design that can be adapted to other agricultural and environmental transitions.

7.2. Practical Implications

Practically, the findings offer a diagnostic and actionable framework for policymakers, extension organizations, and development practitioners. The framework identifies where interventions should be prioritized: strengthening extension and advisory services as the primary entry point, designing targeted financial instruments such as low-interest credit lines, guarantee funds, and climate index-based insurance, embedding climate-smart agriculture in national and regional development plans, and investing in rural digital infrastructure and early warning systems. It also shows that these measures must be complemented by trust-building and participatory mechanisms, including demonstration farms, farmer field schools, and strengthened cooperatives, if resistance to change is to be reduced. Because the framework is organized around generalizable categories rather than a single local case, practitioners in other drought-prone agricultural systems can use it as a rapid diagnostic tool to identify their own priority drivers and barriers and to sequence interventions accordingly, while development agencies and international organizations can use it to design integrated programs that treat extension, finance, institutions, digital infrastructure, and behavior as mutually reinforcing components rather than isolated projects.

7. Research Limitations

This study has several limitations that should be acknowledged. First, although the meta-synthesis covered a substantial body of literature, the evidence base remains uneven across dimensions, with adoption-related studies far outnumbering studies on institutional and behavioral consequences, which may have shaped the relative weight of the identified factors. Second, the Delphi validation relied on a panel of experts whose judgments, while structured and statistically aggregated, remain subject to professional perspectives and contextual priorities, and the removal of gender inequality during the second round illustrates how expert composition can influence outcomes. Third, the framework was validated conceptually rather than empirically through field-level testing, and therefore its predictive and causal claims remain to be examined. Fourth, the study focused on drought-prone agricultural systems and did not examine heterogeneity across different agro-ecological zones or farming systems, which limits the generalizability of specific rankings. Future research should therefore test the proposed framework empirically using farm-level surveys, longitudinal data, and structural modeling, should examine how the relative importance of drivers and barriers varies across regions, farm types, and gender groups, and should apply complementary methods such as MICMAC structural analysis and scenario planning to explore how the identified factors interact dynamically under different climate, policy, and market futures. Comparative studies across countries facing similar climatic and institutional constraints would also help to establish whether the framework holds across diverse developing-country contexts and to refine it into a more broadly applicable tool for climate-smart agriculture transitions.

Declarations

Ethical approval: This study was approved by the Research Ethics Committee of Razi University, Kermanshah, Iran, under ethics code IR.RAZI.REC.1405.067. All procedures were performed in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments.

Consent to Participate

All participants were informed about the objectives and procedures of the study and provided informed consent prior to their participation. Participation was voluntary, and participants were assured of the confidentiality of their responses and their right to withdraw at any stage of the research. All data were collected and analyzed anonymously.

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Authors' Contributions

Amirhossein Alibaygi: Conceptualization, validation, visualization, investigation, supervision, Editing, and Supervision, Writing review of literature.

Masoumeh Taghibaygi: Methodology, Analysis, writing – original draft, Data curation, Methodology, formal analysis, re-sources, Software, Writing original draft**,** project administration**.**

All authors have read and approved the final version of the manuscript.

References

Abate, D., Tesfaye, H., Kassaw, M., Addis, Y., & Mossie, H. (2023). Impact of adopting the climate-smart crop varieties on food security in southwestern Ethiopia. African Journal of Science, Technology, Innovation and Development, 15(5), 590-598. https://doi.org/10.1080/20421338.2022.2157787

Alekseev, I., & Abakumov, E. (2024). Soil organic matter and biogenic-abiogenic interactions in soils of Larsemann Hills and Bunger Hills, East Antarctica. Polar Science, 40, 101040. https://doi.org/10.1016/j.polar.2023.101040.

Ahmadi, F., Nasiriani, K., & Abazari, P. (2008). Delphi technique: A tool in research. Iranian Journal of Medical Education, 8(1), 175-185.

Asadi, A., Barati, A. A., Ahmadi, H., & Golabifar, J. (2022). Analysis of livelihood vulnerability of rural households to climate change in Kermanshah Province. Journal of Rural Research, 13(2), 210-225. https://doi.org/10.22059/jrur.2021.325393.1644.

Asadi, A., Roustaei, M., & Kalantari, K. (2021). Examining the interrelationships of climate-smart agriculture components using the DEMATEL technique. Iranian Journal of Agricultural Economics and Development Research, 52(3), 569-589. https://doi.org/10.22059/ijaedr.2019.260450.66861.

Amiri, S., & Mirkzadeh, A. A. (2022). Examining the factors affecting the adoption of smart water meters among farmers in the Mahidasht Plain. Advanced Technologies in Water Productivity, 2(3), 36-53. https://doi.org/10.22126/ATWE.2022.7873.1020.

Abbasi Karvaneh, Z., Ranjbar, F., Beheshti Al Agha, A., Sharifi, R., & Choghazardhi, H. (2024). The effect of integrated placement-fertilization management on some chemical and biological soil characteristics. Soil Management and Sustainable Production, 14(3), 77-98. https://doi.org/10.22069/ejsms.2024.21760.2120.

Abdollahzadeh, G., Kalger, P., Mahboubi, M. R., & Abedi Sarvestani, A. (2014). Requirements for starting a business in rural areas and the impact of technical and vocational training. Rural Research and Planning, 3(2), 104-127.

Asseldonk, M. V., Girvetz, E., Pamuk, H., Wattel, C., & Ruben, R. (2023). Policy incentives for smallholder adoption of climate-smart agricultural practices. Politics of Technology, 5, 1-15. https://doi.org/10.3389/fpos.2023.1112311.

Awuah, A. K., Stuart-Hill, S., & Trotter-Boardman, D. (2023). Pandora's Box: assessing the current trends and challenges of IWRM in the uMngeni catchment. Water Policy, 25(1), 23-37. https://doi.org/10.2166/wp.2023.183.

Azadi, Y., Yazdanpanah, M., & Mahmoudi, H. (2019). Understanding smallholder farmers' adaptation behaviors through climate change beliefs, risk perception, trust, and psychological distance: Evidence from wheat growers in Iran. Journal of Environmental Management, 250, 109456. https://doi.org/10.1016/j.jenvman.2019.109456.

Bakhshoudehnia, N., Farhadian, H., Saadvandi, M., & Karimi, V. (2026). Adoption of climate-smart agriculture among Iranian farmers based on an extended technology acceptance model. Discover Sustainability, 7(1), 214. https://doi.org/10.1007/s43621-026-02595-1.

Barati, A. A., Azadi, H., Movahhed Moghaddam, S., Scheffran, J., & Dehghani Pour, M. (2024). Agricultural expansion and its impacts on climate change: Evidence from Iran. Environment, Development and Sustainability, 26(2), 5089-5115. https://doi.org/10.1007/s10668-023-02926-6.

Belay, A., Mirzabaev, A., Recha, J. W., Oludhe, C., Osano, P. M., Berhane, Z., Olaka, L. A., Tegegne, Y. T., Demissie, T., Mutsami, C., & Solomon, D. (2024). Does climate-smart agriculture improve household income and food security? Evidence from Southern Ethiopia. Environment, Development and Sustainability, 26, 16711-16738. https://doi.org/10.1007/s10668-023-03307-9

Bene, C., Frankenberger, T. R., Nelson, S., Constas, M. A., Collins, G., Langworthy, M., & Fox, K. (2023). Food system resilience measurement: principles, framework and caveats. Food Security, 15, 1437-1458. https://doi.org/10.1007/s12571-023-01407-y

Benson, T., Natal, A., Wycliffe, T., & Hegarty, J. Ph. (2023). Climate Smart Agriculture (CSA) for Sustainable Agriculture nexus: a tool for transforming food systems. Turkish Journal of Agriculture – Food Science and Technology, 11(6), 1195-1199. https://doi.org/10.24925/turjaf.V11i6.1195-1199.5591.

Billah, M. M., Rahman, M. M., Mahimairaja, S., Lal, A., & Naidu, R. (2025). Constraints and prospects of adoption of climate smart agriculture interventions: Implication for farm sustainability. Climate Smart Agricultural, 2(3), 100066. https://doi.org/10.1016/j.csag.2025.100066.

Bathaiy, S. S., Chizari, M., Sadighi, H., & Alambeigi, A. (2024) .Discriminant Function of the Factors Determining the Farmers' Resilience to Climate Changes (Case Study: Farmers in Ghezel Ozan River Basin, Zanjan Province). Iranian Journal of Agricultural Economics and Development Research, 56 (1), 95-112. DOI: https://doi.org/10.22059/ijaedr.2020.294048.668855.

Baghernejad, J., Sabouri, M. S., Shokati Amghani, M., & Nowruzi, A. (2023). Assessing the sustainability of rural livelihoods of smallholder farmers in selected provinces. Village and Development, 27(3), 45-76.

Bakhshoudehnia, N., Farhadian, H., & Akbari, E. (2024). Application of climate-smart agriculture in Behbahan County. Journal of Extension and Rural Development Research, 2(2), 148-163. https://doi.org/10.30470/jrdes.2024.717748.

Bonyasadi, M., & Shafi Moradi, P. (2026). Analysis of the relationship between human development and good governance with social sustainability in Iran's agricultural sector. Village and Development (In Press).

Chaparinia, F., Hadei, M., Yaghmaeian, K., Hadi, M., & Naddafi, K. (2025). Evaluation of climate indices related to water resources in Iran over the past 3 decades. Scientific Reports, 15(1), 11846. https://doi.org/10.1038/s41598-025-95370-7.

Daum, T., Baudron, F., Birner, R., Qaim, M., & Grass, I. (2023). Addressing agricultural labour issues is key to biodiversity-smart farming. Biological Conservation, 284, 110165. https://doi.org/10.1016/j.biocon.2023.110165

Emami, N. S., Chavoshi, E., Ayoubi, Sh., Honarjoo, N., & Zeraatpisheh, M. (2024). Comprehensive assessment of soil quality in various land uses: a comparative analysis of soil quality index models. Environmental Earth Sciences, 83, 498. https://doi.org/10.1007/s12665-024-11789-7.

Etemadi, M., Mousavi, S. N., & Najafi, B. (2025). Factors affecting climate-smart agriculture development in Fars province, Iran. Caspian Journal of Environmental Sciences, 23(3), 667-683. https://doi.org/10.22124/CJES.2025.8944.

Evertsen, K. F. (2022). The politics of women's lives: gendered re-presentations in Bangladesh's climate change adaptation regime. Climate and Development, 16(2), 199-208. https://doi.org/10.1080/17565529.2022.2072264.

Ewulo, T. A., Akinseye, F. M., Teme, N., Agele, S. O., Yessoufou, N., & Kumar, S. (2025). Factors driving Climate-Smart Agriculture adoption: a study of smallholder farmers in Koumpentum, Senegal. Frontiers in Agronomy, 7, 1552720. https://doi.org/10.3389/fagro.2025.1552720.

Ehsani, M., Nasrinia, F., & Didari, S. (2026). Analysis of precipitation and meteorological drought trends and its zoning in Kermanshah Province. Iranian Journal of Irrigation and Drainage, 1(20), 62-86. https://doi.org/10.22034/idj.2025.512714.2565.

Esmailnejad, M. (2025). Evaluation of climate-smart agriculture strategies appropriate for adaptation to climate change (Case study: Saffron farmers in Sarayan County). Journal of Saffron Research, 13(1), 156-172. https://doi.org/10.22077/jsr.2025.9030.1265.

Etemadi, M., Mousavi, S. N., & Aminifard, A. (2022). Evaluation of factors affecting the adoption of climate-smart agriculture solutions with emphasis on social capital and psychological characteristics. Agricultural Economics, 16(1), 1-33. https://doi.org/10.22034/iaes.2022.538025.1859.

FAO. (2010). Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation. Rome: FAO.

FAO. (2022). Climate-Smart Agriculture Sourcebook (2nd ed.). Rome: FAO. https://www.fao.org/climate-smart-agriculture-sourcebook/en/.

FAO. (2025). The impact of disasters on agriculture and food security 2025. FAO. https://openknowledge.fao.org/handle/20.500.14283/cd3350en.

Filippini, R., Marescotti, M. E., Demartini, E., & Gaviglio, A. (2020). Social networks as drivers for technology adoption: a study from a rural mountain area in Italy. Sustainability, 12(22), 9392. https://doi.org/10.3390/su12229392.

Fallahi, N., & Riahi, V. (2025). Assessing livelihood sustainability in rural settlements around Arak city. Geography and Human Relationships, 8(4), 553-569. https://doi.org/10.22034/gahr.2026.568309.2651.

Gemtou, M., Kakkavou, K., Anastasiou, E., Fountas, S., Pedersen, S. M., Isakhanyan, G., & Pazos-Vidal, S. (2024). Farmers' Transition to Climate-Smart Agriculture: A Systematic Review of the Decision-Making Factors Affecting Adoption. Sustainability, 16(7), 2828.

Ghaffari Farsani, M., & Malekian, M. (2025). The effect of hydrological fluctuations and drought on the diversity of migratory birds in Gandoman Wetland. Natural Environment Journal, 78(4), 649-661. https://doi.org/10.22059/jne.2025.401385.2837.

Goren, H. (2026). Social capital in farmers' climate adaptation: Bonding, bridging and linking ties. Journal of Rural Studies, 121, 103884. https://doi.org/10.1016/j.jrurstud.2025.103884.

Henry, B., Allen, D., Badgery, W., & Bray, S. (2024). Soil carbon sequestration in rangelands: A critical review of the impacts of major management strategies. The Rangeland Journal, 46(3). https://doi.org/10.1071/RJ24005.

Hrabanski, M., & Le Coq, J. F. (2022). Climatisation of agricultural issues in the international agenda through three competing epistemic communities: Climate-smart agriculture, agroecology, and nature-based solutions. Environmental Science & Policy, 127, 311-320. https://doi.org/10.1016/j.envsci.2021.10.022.

Habibi Nokhandan, M., & Masoumpour Amirabadi, R. (2025). The role of agricultural meteorological services in reducing losses and increasing the productivity of rice farmers in northern Iran. Climatology Research, 16(64), 37-51. https://doi.org/10.22034/jcr.2026.583190.1737.

Hosseinpour, Z., Minhaj, M. H., & Kavousi Kalashami, M. (2015). Water, society, and culture: The role of farmers' participation as members of water user cooperatives in improving agricultural water resources management. National Congress of Irrigation and Drainage of Iran. https://sid.ir/paper/871023/fa.

Hamdali, J., Barani, G. A., Ghaderi, K., & Hesari, B. (2018). Evaluation of water management scenarios and the impact of climate change on environmental and agricultural sustainability. Ecohydrology Journal, 5(4), 1203-1217. https://doi.org/10.22059/ije.2018.259906.920.

IPCC. (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report. Cambridge University Press.

IPCC. (2023). Climate Change 2023: Synthesis Report. Geneva: IPCC.

Jafarpour, M., Adib, A., Lotfirad, M., & Kisi, Ö. (2023). Spatial evaluation of climate change-induced drought characteristics in different climates based on De Martonne Aridity Index in Iran. Applied Water Science, 13, 133. https://doi.org/10.1007/s13201-023-01939-w.

JRC. (2026). Climate change could expose over 1 billion people to food crises by 2100. EU Science Hub.

Jamshidi, B., Nakhoda, B., & Alilou, K. (2025). The role of climate-smart agriculture in food security. Ministry of Agricultural Jihad, Agricultural Research, Education and Extension Organization, Agricultural Engineering Research Institute.

Jahangirpour, D., & Zibaei, M. (2021). Optimization of cropping pattern within the framework of climate-smart agriculture objectives: A case study of the Doroodzan irrigation network, Iran. Agricultural Economics and Development (Agricultural Sciences and Industries), 35(4), 407-422. https://doi.org/10.22067/jead.2021.73325.1095.

Kakara, A., & Masambuka-Kanchewa, F. (2025). Revisiting the role of agricultural extension as a technology transfer model: Insights from students' reflections. Journal of Agricultural Education, 66(3), Article 5. https://doi.org/10.5032/jae.v66i3.293.

Karimi, H., & Ataei, P. (2024). An analysis of the perceived effectiveness and upscaling potential of climate-smart agriculture interventions in the Sistan plain, Iran. Journal of Cleaner Production, 460, 142582. https://doi.org/10.1016/j.jclepro.2024.142582.

Karimi, H., & Ataei, P. (2026). The characteristics distinguishing CSA adoption in Iran: The case of Sistan and Baluchistan province. Environmental and Sustainability Indicators, 30, 100518. https://doi.org/10.1016/j.indic.2026.101379.

Karimi, H., Ataei, P., & Pariab, J. (2024). Analysis of Challenges and Barriers to Promoting Climate-Smart Agriculture in Rural Areas of the Sistan Plain: A Qualitative Approach. Journal of Research and Rural Planning, 13(47), 97-116. https://doi.org/10.22067/jrrp.v13i4.2501-1120.

Karimi, V., Karami, E., & Keshavarz, M. (2018). Climate change and agriculture: Impacts and adaptive responses in Iran. Journal of Integrative Agriculture, 17(1), 1-15. https://doi.org/10.1016/S2095-3119(17)61794-5

Keeney, S., Hasson, F., & McKenna, H. P. (2001). A critical review of the Delphi technique as a research methodology for nursing. International Journal of Nursing Studies, 38(2), 195-200. https://doi.org/10.1016/S0020-7489(00)00044-4.

Kelly, B., Palhares, D., & Pruitt, S. (2023). Modeling Corporate Bond Returns. Journal of Finance, 78(4), 1967-2008. https://doi.org/10.1111/jofi.13233.

Keshavarz, M., & Sharafi, H. (2023). Scaling up climate-smart regenerative agriculture for the restoration of degraded agroecosystems in developing countries. Sustainable Production and Consumption, 38, 159-173. https://doi.org/10.1016/j.spc.2023.04.003.

Khoza, S., Beer, L. T. D., Niekerk, D. V., & Nemakonde, L. (2021). A gender-differentiated analysis of climate-smart agriculture adoption by smallholder farmers: application of the extended technology acceptance model. Gender, Technology and Development, 25(1), 1-21.

Kling, M. M., Brittain, C. T., Galford, G. L., Waring, T. M., Hébert-Dufresne, L., Dube, M. P., Sabzian, H., Gotelli, N. J., McGill, B. J., & Niles, M. T. (2024). Innovations through crop switching happen on the diverse margins of US agriculture. Proceedings of the National Academy of Sciences, 121(42), e2402195121. https://doi.org/10.1073/pnas.2402195121.

Kpadonou, R., Owiyo, T., Barbier, B., Denton, F., Rutabingwa, F., & Kiema, A. (2017). Advancing climate smart-agriculture in developing drylands: Joint analysis of the adoption of multiple on-farm soil and water conservation technologies in West African Sahel. Land Use Policy, 61, 196-207. https://doi.org/10.1016/j.landusepol.2016.10.050.

Kafaei Qaeni, A., Soltani, A., Deihimfard, R., & Ajam Nowruzi, H. (2025). Modeling the effect of planting date optimization in mitigating the impact of climate change-induced temperature increase on maize (Zea mays L.) yield in Kermanshah Province. Journal of Crop Production, 18(2), 19-45. https://doi.org/10.22069/ejcp.2025.23047.265001.

Karimi, H., & Ataei, P. (2024). Prediction of the development of climate-smart agriculture interventions in the Sistan Plain. Journal of Geography (Regional Planning), 14(55), 74-90.

Khademi Noushabadi, S. M., Omidi Najafabadi, M., & Mirdamadi, S. M. (2022). Application of climate-smart agricultural technologies in wheat fields: Designing a behavioral model with a Bayesian approach. Journal of Spatial Analysis of Environmental Hazards, 9(4), 105-124.

Khaledi, F., Zarafshani, K., Mirkzadeh, A. A., & Sharafi, L. (2016). Examining the factors affecting farmers' adaptation to climate change (Case study: Wheat farmers in Sarpol-e Zahab). Rural Research, 6(3), 655-678.

Khorajpour, H., Hejazipour, Z., Alijani, B., & Naserzadeh, M. H. (2022). Synoptic statistical analysis of extreme heat and its effect on wheat yield in Kermanshah Province. Journal of Applied Geographical Sciences Research, Online Publication.

Li, L., Ge, Y., & Zhao, J. (2024). Capacitive soil moisture sensor based on molybdenum disulfide. Smart Agriculture, 6(1), 18. https://doi.org/10.12133/j.smartag.SA202309022.

Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S., & Branca, G. (2018). Climate Smart Agriculture Building Resilience to Climate Change. In Natural Resource Management and Policy (Vol. 52). Springer. https://doi.org/10.1007/978-3-319-61194-5_13.

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., Henry, K., Hottle, R., Jackson, L., Jarvis, A., Kossam, F., Mann, W., McCarthy, N., Meybeck, A., Neufeldt, H., Remington, T., Thi Sen, P., Sessa, R., Shula, R., Tibu, A., & Torquebiau, E. F. (2014). Climate-smart agriculture for food security. Nature Climate Change, 4, 1068-1072. https://doi.org/10.1038/nclimate2437.

Louimi, K., & Khosravipour, B. (2024). Effects of innovation adoption on rural development. Geography and Human Relationships, 6(24), 624-634. https://doi.org/10.22034/gahr.2024.448797.2073.

Ma, W., & Rahut, D. B. (2024). Climate-smart agriculture: Adoption, impacts, and implications for sustainable development. Mitigation and Adaptation Strategies for Global Change, 29(5), Article 44. https://doi.org/10.1007/s11027-024-10139-z.

Mohammadi, H. R., Marroudi, M., Banayan, M., Asgharipour, M. R., & Fanaei, H. R. (2018). The effect of climate change on the growth period length and phenological stages of wheat in the Zabol region. Journal of Plant Ecophysiology, 10(34), 181-191.

Mahmoudi Cheshmehkaboud, S., & Lashkari, H. (2026). The effect of climatic changes (temperature, precipitation, and humidity) on the land subsidence trend in Kermanshah Province: A case study of 13

stations. Geography and Human Relationships, 9(33), 377-394. https://doi.org/10.22034/ghr.2026.579070.2707.

Marzban, Z., Asgharipour, M. R., Gonbari, A., Nikouei, A. R., Ramroudi, M., & Seyedabadi, E. (2020). Reducing environmental impacts through redesigning the cropping pattern using life cycle assessment (LCA) and multi-objective programming (MOP) (Case study: Eastern Lorestan Province). Journal of Agricultural Science and Sustainable Production, 30(3), 311-330.

Mousaei, M. (2025). Identifying the factors affecting the adoption of smart agriculture in the face of climate variability: A case study of farmers in Fars Province. Journal of Agricultural Economics and Development, 33(131), 210-249.

Mansouri Daneshvar, M. R., Ebrahimi, M., & Nejadsoleymani, H. (2019). An overview of climate change in Iran: facts and statistics. Environmental Systems Research, 8(1), 1-10. https://doi.org/10.1186/s40068-019-0135-3.

Mazhar, R., Ghafoor, A., Xuehao, B., & Wei, Z. (2021). Fostering sustainable agriculture: Do institutional factors impact the adoption of multiple climate-smart agricultural practices among new entry organic farmers in Pakistan? Journal of Cleaner Production, 283, 124620.

Memarbashi, P., Mojarradi, G., & Keshavarz, M. (2022). Climate-Smart Agriculture in Iran: Strategies, constraints and drivers. Sustainability, 14(23), 15573. https://doi.org/10.3390/su142315573.

Mitra, A., & Barua, P. (2024). Review on Climate Smart Agriculture Practice. Journal of Climate Change, 10(1).

Mnukwa, M. L., Mdoda, L., & Mudhara, M. (2025). Assessing the adoption and impact of climate-smart agricultural practices on smallholder maize farmers' livelihoods in Sub-Saharan Africa: a systematic review. Frontiers in Sustainable Food Systems, 9, 1543805. https://doi.org/10.3389/fsufs.2025.1543805

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group. (2010). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. International Journal of Surgery, 8(5), 336-341.

Moser, D., Vance, C., Collard, J., Rieger, M., Anggraini, E., Merico, A., & Schlüter, A. (2026). Cross-cultural evidence on cognitive biases in climate protection. Earth's Future, 14(8). https://doi.org/10.1029/2025EF007697.

Motamedi, A., Gohari, A., & Torabi Haghighi, A. (2023). Three-decade assessment of dry and wet spells change across Iran, a fingerprint of climate change. Scientific Reports, 13, 2888. https://doi.org/10.1038/s41598-023-30040-0.

NASA. (2025). Temperatures Rising: NASA Confirms 2024 Warmest Year on Record.

Ndabaningi, A., Tirivangasi, H. M., & Bastiaensen, J. (2023). An Afrocentric Intersectional Conceptual Framework for Smallholder Microfinance and Climate Adaptation in Chimanimani, Zimbabwe. In The

Palgrave Handbook of Global Social Problems (pp. 1-28). Springer. https://doi.org/10.1007/978-3-030-68127-2_355-1.

Nowruzi, M., & Hayati, D. (2015). Factors affecting sustainable rural livelihoods from the perspective of farmers in Kermanshah Province. Iranian Journal of Agricultural Extension and Education Sciences, 11(1), 127-144. https://doi.org/20.1001.1.20081758.1394.11.1.9.3.

Niroumand, L., Zarei, H., & Tajik Esmaili, S. (2020). The role of participatory communication in training farmers in new production technologies, 12(53), 77-95. https://doi.org/10.22092/jaear.2021.343405.1738.

Nelson, K., Tran, N. B., Cuong, O. Q., & Trang, V. H. (2024). Enabling Environment to Scale AWD and Rice Straw Management: A 6-Step Approach. CGIAR Initiative on Low Emission Food Systems.

Nozari, M., Firoozzare, A., Boccia, F., Ghazanfari, S., & Covino, D. (2026). Climate-smart agriculture adoption intensity in a semi-arid agricultural landscape: drivers and disparities. Journal of the Science of Food and Agriculture. Advance online publication. https://doi.org/10.1002/jsfa.70920.

Nshakira-Rukundo, E., Tabe-Ojong, M. P., Gebrekidan, B. H., Agaba, M., Surendran Padmaja, S., & Dhehibi, B. (2026). Adoption of climate-smart agricultural technologies and practices in fragile and conflict-affected settings: A review and meta-analysis. Ruhr Economic Papers 1113, RWI - Leibniz-Institut für Wirtschaftsforschung. https://doi.org/10.4419/96973291.

Oduntan, O., & Obisesan, A. (2022). Factors influencing adoption of climate smart agricultural practices among maize farmers in Ondo State, Nigeria. Journal of Economics and Allied Research, 7(4), 164-177.

Ogisi, O. D., & Begho, T. (2023). Adoption of climate-smart agricultural practices in sub-Saharan Africa: a review of the progress, barriers, gender differences and recommendations. Farming System, 1(2), 100019.

Olagunju, K. O., Olagunju, K. A., Ogunniyi, A. I., Omotayo, A. O., & Oyetunde-Usman, Z. (2023). To own or not to own? Land tenure security and production risk in small-scale farming. Land Use Policy, 127, 106584. https://doi.org/10.1016/j.landusepol.2023.106584.

Othmani, A., Bouhouel, I., & Ayed, S. (2023). Cereal drought adaptation strategies. GSC Advanced Research and Reviews, 17(1), 001-010. https://doi.org/10.30574/gscarr.2023.17.1.0225.

Pagliacci, F., Defrancesco, E., Mozzato, D., Bortolini, L., Pezzuolo, A., Pirotti, F., & Gatto, P. (2020). Drivers of farmers' adoption and continuation of climate-smart agricultural practices. A study from northeastern Italy. Science of The Total Environment, 710, 136345.

Pakrooh, P., & Kamal, A. (2023). Food security and climate change in Iran: A review of challenges and opportunities. Environmental Science and Pollution Research, 30(15), 42567-42584. https://doi.org/10.1007/s11356-023-25567-8.

Parra-López, C., Ben Abdallah, S., Garcia-Garcia, G., Hassoun, A., Sánchez-Zamora, P., Trollman, H., Jagtap, S., & Carmona-Torres, C. (2024). Integrating digital technologies in agriculture for climate change adaptation and mitigation: State of the art and future perspectives. Computers and Electronics in Agriculture, 226, 109412. https://doi.org/10.1016/j.compag.2024.109412.

Petticrew, M., & Roberts, H. (2006). Systematic reviews in the social sciences: A practical guide. Blackwell Publishing. https://doi.org/10.1002/9780470754887.

Popay, J., Roberts, H., Sowden, A., & Petticrew, M. (2006). Guidance on the conduct of narrative synthesis in systematic reviews. ESRC Methods Programme. https://doi.org/10.13140/2.1.1018.4643.

Qobadi Aliabadi, S., Aghei, H., & Farhadian, H. (2022). Examining the factors affecting farmers' perception of climate change risk and the impact of these factors on their adaptive behaviors (Case study: Kermanshah County). Journal of Regional Planning, 12(46), 333-347.

Qamarnia, H., & Nakoukish, M. (2025). Site selection of areas suitable for olive, pomegranate, and citrus cultivation for proper cropping planning and water resource allocation in Kermanshah Province using Geographic Information Systems (GIS). Advanced Technologies in Water Productivity, 5(1), 35-50. https://doi.org/10.22126/ATWE.2024.11172.1141.

Qanbari, Y., Hajarian, A., Ansari, R., & Kiani, F. (2012). Identifying the factors and barriers to rural women's participation in agricultural activities (Case study: Fereydounshahr County). Rural Research and Planning, 2, 71-87. [InPersian].

Rahimi, M. (2022). An indigenous approach to confronting the value challenges of technology. Sharif University of Technology Press.

Razzaqi Bourkhani, F., Shavikloo, N., & Shokati Almasi, M. (2018). Fundamental risk management strategies in Iran's agricultural development. First National Conference on Solutions for Achieving Sustainable Development in Agriculture, Natural Resources, and Environment. https://civilica.com/doc/197314/.

Rafiei Sefiddashti, M., Mirdamadi, S. M., Farajollah Hosseini, S. J., & Shokri, S. (2024). Explaining the pattern of factors affecting the capacity-building of extension experts in climate-smart agriculture development in the northwestern provinces of the country. Journal of Agricultural Economics and Development, 38(3), 315-333. https://doi.org/10.22067/jead.2024.88543.1276.

Ranjbar, A., Kalantari, K., & Asadi, A. (2012). Measuring social capital among members of agricultural production cooperatives in Markazi Province. Journal of Cooperation and Agriculture, 1(4), 1-17. https://doi.org/20.1001.1.27835464.1391.1.4.1.9.

Ranjbar, A., Mousavi, S. N., & Najafi, B. (2025). Cropping pattern reform within the framework of climate-smart agriculture and its role in sustainable water resources management: Application of multi-objective programming and system dynamics models. Journal of Modern Environmental Sciences, 4(23), 1009-1032.

Regmi, S., & Paudel, B. (2024). Climate-smart agriculture: A review of sustainability, resilience, and food security. Archives of Agriculture and Environmental Science, 9(4). https://doi.org/10.26832/24566632.2024.0904028

Ricart, S., Gandolfi, C., & Castelletti, A. (2023). Climate change awareness, perceived impacts, and adaptation from farmers' experience and behavior: A triple-loop review. Regional Environmental Change, 23(3), 82. https://doi.org/10.1007/s10113-023-02078-3.

Rousta, I., Izadian, S., Olafsson, H., Dalvi, M., & Krzyszczak, J. (2026). Warming and Drying Intensification Across Iran's River Basins (1950-2040): Historical Trends and LightGBM-Based Projections. Atmosphere, 17(5), 446. https://doi.org/10.3390/atmos17050446.

Saadu, B., Ibrahim, H. Y., Nazifi, B., & Mudashiru, A. (2024). Adoption of climate-smart agricultural practices and its impact on smallholder farming households in some rural areas of North-Western Nigeria. Agricultura Tropica et Subtropica, 57(1), 23-34. https://doi.org/10.2478/ats-2024-0003.

Sadeghi, S. H., Chamani, R., Kalehhouei, M., & Haji, K. (2025). Health variability based on SPI and estimating median and mean health indices in watersheds and townships of Kermanshah Province, Iran. Environment, Development and Sustainability, 27(12), 30179-30199.

Sandelowski, M., & Barroso, J. (2003). Toward a metasynthesis of qualitative findings on motherhood in HIV-positive women. Research in Nursing & Health, 26(2), 153-170.

Soleimani, M. (2023). Adaptation to climate change from the perspective of farmers and experts (Rostam County). Journal of Spatial Planning, 13(2), 95-109. https://doi.org/10.22108/SPPL.2023.138568.1740.

Siyar Khalaj, H., Hashemianfar, S. A., Salehi, S., & Abdollahi, A. S. (2022). Farmers' perception of social barriers and facilitators of adaptation to climate change. Economic Sociology and Development, 11(2), 25-55. https://doi.org/10.22034/JEDS.2022.50621.1623.

Sabounchi, A., Zarafshani, K., & Rostami, F. (2023). Assessing the resilience of cropping systems to climate change using the Sharp scale (Case study: Saffron farmers in Kermanshah Province). Journal of Saffron Research, 11(1), 131-159. https://doi.org/20.1001.1.23453869.1402.11.1.10.1.

Salehi Tahbaz, N., Koupahi, M., & Nazari, M. R. (2010). Examining the performance of participatory irrigation management in Iran (Tajan water user cooperative). Journal of Agricultural Economics and Development, 24(2). https://doi.org/10.22067/jead2.v1389i2.3937.

Sayyidi Mohammadi, S., Tavakoli, M., Zarafshani, K., Hosseinzadeh, M., & Amiri, F. (2021). Predicting the effects of climate change on temperature and precipitation using general circulation models: A strategy for sustainable agriculture (Case study: Kermanshah County). Journal of Environmental Science and Technology, 23(6), 15-31.

Schmidt, R. C. (1997). Managing Delphi surveys using nonparametric statistical techniques. Decision Sciences, 28(3), 763-774. https://doi.org/10.1111/j.1540-5915.1997.tb01330.x.

Schulze, K. (2024). The soft channels of policy diffusion: Insights from local climate change adaptation policy. Policy Studies Journal, 1-26. https://doi.org/10.1111/psj.12555.

Senyolo, M. P., Long, T. B., Blok, V., & Omta, O. (2018). How the characteristics of innovations impact their adoption: An exploration of climate-smart agricultural innovations in South Africa? Journal of Cleaner Production, 172, 3825-3840.

Simutowe, E., Ngoma, H., & Thierfelder, C. (2025). Impacts of climate smart agriculture on livelihoods in sub-Saharan Africa: A meta-analysis. Outlook on Agriculture, 54(3), 234-245. https://doi.org/10.1177/00307270251322797.

Soltani, A., Pourshirazi, S., Torabi, B., Rahban, S., & Alimagham, S. (2025). Assessing climate change impacts on plant production and irrigation water demand at country level: analysis for Iran. Journal of Agriculture and Environment for International Development, 119(1), 393-412. https://doi.org/10.36253/jaeid-16757.

Tohidimoghadam, A., Poursaeed, A., Bijani, M., & Eshraghi Samani, R. (2024). Explanation a Gardeners' Sustainable Livelihood Resilience Model to Climate Change in Hamadan Province. Iranian Journal of Agricultural Economics and Development Research, 55(3), 447-466. https://doi.org/10.22059/ijaedr.2024. 364759. 669253.

Tousi, A., Niknami, M., Hosseini, S. F., & Omidi Najafabadi, M. (2021). Modeling farmers' behavior in optimal agricultural water consumption management based on climate-smart agriculture in Pakdasht County: Application of the theory of planned behavior. Journal of Extension and Agricultural Education Research, 14(1), 54-70.

UNFCCC. (2025). Sharm el-Sheikh joint work on implementation of climate action on agriculture and food security. United Nations Framework Convention on Climate Change.

Valipour Parkouhi, S., Valipour Parkouhi, S., & Arab, A. (2026). Analyzing barriers to the adoption of climate-smart agriculture (CSA) by farmers: An application of UTAUT and decomposed fuzzy approach. Industrial Management Journal, 18(3), 285-320. https://doi.org/10.22059/imj.2026.414885.1008319.

van Gameren, E., García-Mora, F., & Mora-Rivera, J. (2024). Does use of formal and informal credit reduce poverty in rural Mexico? Development Policy Review, 42(5), e12798. https://doi.org/10.1111/dpr.12798.

van Valkengoed, A. M., & Steg, L. (2019). Meta-analyses of factors motivating climate change adaptation behaviour. Nature Climate Change, 9, 158-163. https://doi.org/10.1038/s41558-018-0371-y.

Vasavi, S., Anandaraja, N., Murugan, P. P., Latha, M. R., & Pangayar, S. R. (2025). Climate-smart agriculture technologies: Trends, acceptance and adoption constraints among farmers - A systematic literature review and bibliometric analysis. Plant Science Today, 12(3). https://horizonepublishing.com/journals/index.php/PST/article/view/6508.

Vecchio, Y., et al. (2026). Bridging Information, Institutions, and Livelihoods: A Systematic Review of Climate-Smart Agriculture Adoption and Food Security among Smallholders. Journal of Regional and Rural Studies, 4(1). https://doi.org/10.21776/rrs.v4i1.82.

Veysi, S., & Nouri, M. (2026). Spatiotemporal dynamics of single and compound drought-heatwave extremes impacts on water productivity. Journal of Hydrology: Regional Studies, 65, 103370. https://doi.org/10.1016/j.ejrh.2026.103370.

WMO. (2025). State of the Global Climate 2024. Geneva: World Meteorological Organization.

Wollburg, P., Markhof, Y., Bentze, T., & Ponzini, G. (2024). Substantial impacts of climate shocks in African smallholder agriculture. Nature Sustainability, 7(11), 1525-1534. https://doi.org/10.1038/s41893-024-01411-w.

Xie, G., Su, X., & Huang, M. (2024). Social Media, Knowledge Management, and Learning in Farmer Innovation. HighTech and Innovation Journal, 5(2), 295-311. https://doi.org/10.28991/HIJ-2024-05-02-06.

Yazdanpanah, M., Hayati, D., Hochrainer-Stigler, S., & Zamani, G. H. (2014). Understanding farmers' intention and behavior regarding water conservation in the Middle-East and North Africa: a case study in Iran. Journal of Environmental Management, 135, 63-72. https://doi.org/10.1016/j.jenvman.2014.01.016.

Zakaria, A., Azumah, S. B., Appiah-Twumasi, M., & Dagunga, G. (2020). Adoption of climate-smart agricultural practices among farm households in Ghana: The role of farmer participation in training programmes. Technology in Society, 63, 101338.

Zhao, J., Liu, D., & Huang, R. (2023). A review of climate-smart agriculture: recent advancements, challenges, and future directions. Sustainability, 15(4), 3404. https://doi.org/10.3390/su15043404.