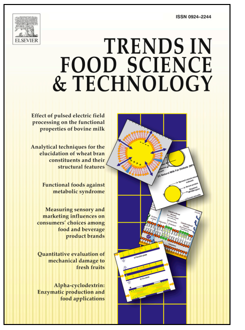
Journal Pre-proof



Contributions of Climate Smart Agriculture Toward Climate Change Adaptation and Food Security: The Case of Mazandaran Province, Iran

Imaneh Goli, Zita Kriaučiūnienė, Ru Zhang, Masoud Bijani, Pourya Kabir Koohi, Seyed Amirreza Rostamkalaei, David Lopez-Carr, Hossein Azadi

PII: S0924-2244(24)00329-7

DOI: https://doi.org/10.1016/j.tifs.2024.104653

Reference: TIFS 104653

To appear in: *Trends in Food Science & Technology*

Received Date: 3 September 2023

Revised Date: 29 July 2024

Accepted Date: 1 August 2024

Please cite this article as: Goli, I., Kriaučiūnienė, Z., Zhang, R., Bijani, M., Kabir Koohi, P., Rostamkalaei, S.A., Lopez-Carr, D., Azadi, H., Contributions of Climate Smart Agriculture Toward Climate Change Adaptation and Food Security: The Case of Mazandaran Province, Iran, *Trends in Food Science & Technology*, https://doi.org/10.1016/j.tifs.2024.104653.

Contributions of Climate Smart Agriculture Toward Climate Change Adaptation and Food Security: The Case of Mazandaran Province, Iran

Imaneh Goli[1], Zita Kriaučiūnienė[2], Ru Zhang[3,*], Masoud Bijani[4], Pourya Kabir Koohi[5], Seyed Amirreza Rostamkalaei[6], David Lopez-Carr[7], Hossein Azadi[1]

[1]*Department of Economics and Rural Development, Gembloux Agro-Bio Tech, University of Liège, Gembloux, Belgium*

[2]*Department of Agroecosystems and Soil Sciences, Agriculture Academy, Vytautas Magnus University, K. Donelaičio Str. 58, LT-44248 Kaunas, Lithuania*

[3]*School of Law, Anhui University of Finance and Economics, Bengbu, PR China*

[4]*Department of Agricultural Extension and Education, College of Agriculture, Tarbiat Modares University (TMU), Tehran, Iran*

[5]*Department of Architecture and Urban Planning, Shahid Beheshti University, Tehran, Iran*

[6]*Department of Industrial Engineering, Islamic Azad University, West Tehran Branch, Iran*

[7]*Department of Geography, University of California, Santa Barbara, United States*

[*]Corresponding author: Email: 836059768@qq.com

Abstract

Background: To improve food security in the face of climate change, climate-smart agriculture is a method for restructuring and reorienting agricultural systems.

Scope and approach: This study aimed to examine whether climate-smart agriculture can enhance adaptation to climate change impacts and achieve food security. To fulfill this purpose, 180 agricultural specialists from Mazandaran Province, Iran, were chosen using the proportional stratified random selection approach, and a structured questionnaire was used to gauge their perspectives.

Key findings and conclusions: The results showed that innovation, investment, and supportive institutions would be crucial in encouraging the use of climate-smart agriculture. Moreover, this study underscored the importance of improving farmers' awareness of the benefits of agricultural insurance. By enhancing insurance services specifically tailored to agricultural needs, both by the public and private sectors, it can significantly promote the adoption and implementation of climate-smart agricultural practices. Climate-smart agriculture may considerably increase food security by serving as a mediator between climate change adaptation and food security. It is indispensable to prepare the agricultural sectors in order to rapidly change the environmental landscape, utilize new technologies, increase the investment of public and private institutions, and provide more government support for climate-smart farming methods. The findings of this study could be employed to design suitable policies, investments, and institutional measures needed to properly monitor climate-smart agriculture and achieve food security.

Keywords Climate crises; Vulnerability; Food safety; Agricultural productivity; Mitigation; Risks and responses.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) claims that climate change (CC) has significant destructive effects on the agricultural sector and is a major danger to rural and urban communities (IPCC, 2019). As farmland productivity and income decline, market relations are disrupted, and smallholder and marginalized farmers become more vulnerable (IFPRI, 2020). As the negative impacts of CC continue, investors' motivation will decline, beneficiaries' risk taking will weaken, and farmers will be forced to put more pressure on resources to maintain production, increase off-farm inputs, and exacerbate instability (Katsini et al., 2022). These activities, in turn, increase climate instability and, consecutively, increase the rate of production and greenhouse gas emissions. It is obvious that without a change in the vision of conventional agriculture and its economic and social dimensions, production systems will not be able to provide food security and combat CC (FAO, 2013). Increasing food security in partnership by mitigating the risks of CC, adaptation, and protecting natural resources and vital ecosystem services requires changing agricultural systems to produce more products with higher productivity (Fuss et al., 2015; Ali, 2021). Therefore, higher efficiency per unit consumption, fewer changes, and more stability in output can lead to greater flexibility to long-term changes and greater resilience to hazards and turbulence (Fahad & Wang, 2018).

The concept of Climate Smart Agriculture (CSA) was first introduced by the FAO during the Hague Conference on Agriculture, Food Security, and CC in 2010 (FAO, 2010). The objective was to incorporate CC knowledge into strategies for implementing sustainable agriculture, with the goal of mitigating adverse impacts and promoting sustainability in alignment with the Sustainable Development Goals (SDGs). Furthermore, it finds techniques for trading and sharing efforts as a basis for organizing, considers food security, flexibility, and mitigation of CC hazards, and changes policy from a farm to a global scale in response to CC (Saj et al., 2017). Indeed, CSA attempts to achieve SDGs across various temporal and spatial scales, integrating policies to sustain productivity, enhance economic aspects, and utilize all social potentials. However, gender issues should also be taken into consideration in this comprehensive approach (Abegunde et al., 2019; Lu et al., 2019).

However, the agricultural sector in Iran faces many challenges in realizing food security. For example, CC and climate shocks are among the main issues that have made the agricultural sector vulnerable to food security and nutrition (Ardakani et al., 2017; Akbari et al., 2021; Atamaleki et al., 2020). Over the last years, rising temperatures, changing rainfall patterns, and severe water shortages in the agricultural sector have led to increased pressure on water resources, especially groundwater aquifers (Modarres et al., 2016). The results of studies by Plunge et al. (2022) Ali & Erenstein (2017) and Moradi et al. (2013) showed a decrease in the yield of many crops in response to CC (Moradi et al., 2013). On the other hand, 1.3% to 4.5% of the population in Iran suffer from malnutrition. Karandish & Hoxtra (2017) stated that even though 70% of agricultural production is provided by the villagers, most of the people in our world with malnutrition are villagers whose main livelihood depends on agriculture.

Exploring the potential of CSA objectives is crucial, particularly given the significance of CC in Iran's agricultural sector and its interaction with food security, climatic events, and human activities. Therefore, the primary goal of the current study is to examine how CSA impacts CC adaptation and food security from the viewpoint of agricultural specialists in the province of Mazandaran (located in northern Iran). To achieve this goal, in this study, three important dimensions were examined: 1) The role of CSA components in Adaptation to Climate Change (ACC), 2) ACC's impact in achieving food security, and 3) the CSA's contribution to ensuring food security. This is the first time that the study like this has been conducted in Iran. This is the first time such a study has been conducted in Iran. To the best of our knowledge, there hasn't been any research done in Iran up to this point that looks at all the CSA components together with the aspects of food security and the role of ACC as a mediating factor. This is the new aspect of this study that makes it unique. The findings of this study can be beneficial for designing the policies, investments, and institutional mechanisms required to efficiently expand CSA and attain food security. It gives academics and decision-makers a proof-of-concept on how to consider and evaluate farmer adaptation to CC in the future. The findings of this study offer valuable insights that could empower farmers and policymakers in making informed decisions about their adaptation timelines. Furthermore, it has the potential to significantly enhance future policy analyzes in the realm of CSA and help identify optimal strategies to enhance food security.

2. Literature review

Under the current realities of CC, CSA is a strategy for altering and reorienting agricultural systems to support food security. CSA strives to induce biodiversity, efficiency, self-sufficiency, self-regulation, and self-reliance in agricultural systems by combining plants, livestock, and crops. Enhancing pest and disease management, water, and nutrient management, as well as landscape, grassland, and forest management, are additional elements that can enhance adaptability and reduce the risk of food insecurity (Fig. 1) (Partey et al., 2018; Thornton et al., 2014). The ultimate destination of CSA is sustainability signifying that agricultural systems have the greatest flexibility to CC and at the same time provide food security (Hrabanski & Le Coq, 2022).

[Insert Figure 1]

In this regard, Makate (2019) argued that effective, complementary, and supportive situational activities toward scaling can lessen farmer difficulties, alleviate adoption limitations, and increase scaling processes' sustainability, all of which can improve the societal effects of CSA practices and technology. However, Amadu et al. (2020) thought that by boosting crop yields in the face of growing climatic unpredictability and severe weather shocks, policies and funding sources that support CSA might significantly affect food security in low-income, dryland areas like southern

Malawi. In addition, Totin et al. (2018) showed in their study that rethinking the strategy to promote CSA technologies by including technology packages and institutional supporting factors might create prospects for efficient CSA scaling. The shift to CSA will rely heavily on technological advancements. However, socioeconomic barriers to CSA technical innovation dissemination exist (Long et al., 2016). Besides this, Meinzen-Dick et al. (2013) mentioned that institutions and institutional arrangements are essential in giving information, allowing innovation, facilitating investment, and providing insurance for CSA initiatives and programs. According to Zougmore et al. (2018) in the context of CC, CSA looks to be a step forward in increasing agricultural productivity, rural livelihoods, and farmers' and production systems' ability for adaptation, while also contributing to mitigation. CSA has been mainstreamed into agricultural development plans through the establishment of regional, sub-regional, and national CC policies and strategies aimed at reducing CC and enhancing African people's adaptive ability. Financial commitments from the government and development organizations will be essential for boosting the widespread use of CSA.

Based on the previous studies (e.g., Amadu et al., 2020; Totin et al., 2018; and Long et al., 2016) relatively few studies have been done on these variables in the context of Iran, and further studies in this regard seem necessary. In this study, CSA has been applied to several parts of agriculture, spanning from field-scale agricultural techniques to food supply networks and food systems generally, by finding the gap in the prior research and relying on innovative conceptualization. A wide range of institutions, policies, finances, safety nets, capacity-building, and assessment have all been highlighted as supporting CSA, in addition to agricultural methods and outcomes. A list of studies on the relationship between CSA and food security is shown in the Appendix. To gain a deeper understanding of how CSA could help farmers in adapting to CC and increase their food security in the forthcoming years, the following research questions were addressed:

1) How can CSA enhance ACC?
2) How can CSA improve food security through ACC?

3. Methodology

3.1. Study area

Mazandaran province is located in the north of the Iran and on the southern shore of the Caspian Sea, with an area of 24,091 km^2 and a population of 2,602,008 people (Iran Statistics Center, 2018) (Fig. 2). In this province, the northern part is mainly plain and coastal and the southern part is mostly mountainous. Based on the region's terrain, temperature, and precipitation patterns, Mazandaran is categorized into two climatic types: a mountainous climate and a temperate Caspian climate. Mountainous regions with moderate temperatures and those with a frigid climate make up its mountainous climate. The western areas of Mazandaran are classified by Domartan as being highly humid, the center regions as being humid, and the eastern Mediterranean and mountainous regions as being semi-humid (Mazandaran Meteorological Organization, 2018). The average annual temperature in this province is 17.6^{o}C, and over the past ten years (2009-2019), there have been roughly 700 millimeters of yearly rainfall on average (Meteorological Department of Mazandaran Province, 2019). Additionally, about 78% of the people in this region work in agriculture. Mazandaran province in Iran ranks highest in the production of rice and citrus, representing its most significant agricultural and horticultural commodities (Mazandaran Agricultural Jihad Organization, 2020). CC in the region is evident regarding the temperature fluctuations trend, especially in recent years (Daneshvar et al., 2019;

Goli et al., 2020). Various factors have caused this province, as the agricultural hub of Iran, to be under serious pressure from CC (Meteorological Department of Mazandaran Province, 2020), and its agricultural products have suffered a lot of damage. These include recent temperature increases; a significant decrease in the amount of water resources in Mazandaran in the coming years; changes in rainfall pattern, intensity, timing, and location; changes in land use; the building of villas; livestock grazing in the highlands; and emigration to the suburbs (Kavianpoor et al., 2019). Since the economy of more than half of the population of this province is provided by the cultivation of crops and horticulture, the occurrence of the climate crisis has had a severe impact on people's livelihoods, especially in rural areas. As a result, ACC appears to be necessary and critical in increasing the agricultural sector's flexibility, protecting farmers' livelihoods, and ensuring food security in this province.

[Insert Figure 2]

3.2. Research and sampling methods

This study was conducted from July 2020 to March 2021. In this regard, pre-trial preparation or pre-study preparation, as well as statistical analysis and reporting, is not considered. It is also causal-relational since the causal relationship between the variables is investigated. In this study, stratified sampling with proportionate assignment was the sampling method utilized. The research population was selected at random from the Mazandaran Province's Jihad-e Agriculture Organization's male and female specialists. The research sample size was calculated using Cochran's formula (Eq 1). To calculate Cochran's formula, it is necessary to estimate the variance. Therefore, 30 preliminary samples of the arranged questionnaire were completed by agricultural experts of Golestan province. In this study, agricultural expert refers to an individual with a university degree who offers services related to design and calculations tailored to specific situations and expectations and oversees project implementation in the agricultural sector. Finally, by replacing the symbols in Cochran's formula, the acceptable sample size for the statistical population (agricultural experts of Mazandaran Agricultural Jihad Organization) was equal to 180 people.

$n=(Nt^2S^2)/(Nd^2+t^2S^2)=((2194(1.96)^2)\times(3.42)^2)/((2194(0.5)^2+((1.96)^2(3.42)^2)=180$ Eq (1)

$d = t\frac{s}{\sqrt{n}} = 0.5$

n= acceptable sample size (180)

N= the size of the whole population (2194)

t= the fixed value of “t“ with 95% confidence or 5% error (t =1.96)

S= variance of the dependent variable in the preliminary test (S^2=?)

d= error allowed (0.5)

3.3. Survey instrument

A questionnaire was created as the primary research instrument to answer the research problem and achieve the research objectives (the questionnaire is provided in the attachment). This questionnaire examined research questions in four parts: 1) individual characteristics, 2) components of food security, 3) components of CSA, and 4) ACC. This questionnaire examined research questions in four parts: 1) individual characteristics, 2) components of food security, 3) components of CSA, and 4) ACC. CSA comprised 54 items. CSA included five factors: “awareness and information” (8 items), “insurance of agricultural products against climatic changes” (10 items), “investing in CSA (Inv-CSA)” (10 items), “innovation in CSA (Inn-CSA)” (14 items), and “supporting institutions in CSA (Sup-CSA)” (14 items). ACC was measured with 21 items. Food security comprised four factors: “food availability (F-AVA)” (9 items), “food accessibility (F-ACE)" (7 items), "food consumption/use (F-COU)" (5 items), and "food security sustainability (FS-SUS)" (7 items). The items were measured with a 5-point Likert scale (for CSA: 1= completely agree; 2= agree; 3=relatively agree; 4= disagree; and 5 = completely disagree and for other variables: 1=Very high; 2= High; 3=Medium; 4= Low; and 5 = Very low). The information was then gathered utilizing this questionnaire, which served as a guide for this study. The views and suggestions of supervisors, researchers, and experts in the agricultural sector (private and public sectors) of Mazandaran province were used to verify the questionnaire's validity, and after the required changes, it was established that the questions could be addressed in order to assess the research's substance and qualities. A pilot study with 30 samples was undertaken to test the validity of the questionnaires completed by agricultural experts in Golestan province, and the questionnaires were analyzed through Cronbach's alpha, sequential theta, and composite reliability using Spsswin_{26} and Lisrel 10.3 software (Goli et al., 2020). The result of Cronbach's alpha coefficient for the mentioned questionnaire was 0.842 (CSA=0.811; adaptation=0.841; food security=0.876). Moreover, the result obtained from the sequential theta was 0.879 (CSA=0.816; adaptation=0.901; food security=0.921), and the result of the composite reliability was 0.864 (CSA=0.812; adaptation=0.880; food security=0.901). All these values are higher than 0.70 and this indicates the reliability of the research questionnaire.

The Sobel test was also employed to evaluate the relevance of the mediating impact of adaptation to the link between CSA and food security in this study.

$$z - value = \frac{\mathrm{a} \times \mathrm{b}}{\sqrt{(b^2 \times sa^2) + (a^2 \times sb^2) + (sa^2 \times sb^2)}} \qquad \text{Eq (2)}$$

where:

"a" is the value of the independent and mediating variables' route coefficients.

The mediator's route coefficient to the dependent variable is denoted by “b”. “Sa” is the route between the independent variable and the mediator's standard error. “Sb” is the error for the path between the mediator and the dependent variable.

4. Results

4.1. Demographic features

The demographic analysis of the study participants reveals that approximately 58% of the experts were female, while 42% were male. The experts ranged in age from 27 to 59, with 35 being the average age and 27 being the youngest. According to the results, the average work experience of experts was 13 years. The lowest work experience among the subjects was 3 and the highest was 21 years. The majority of specialists (52.7%) had a bachelor's degree, followed by a master's degree (43.3%).

4.2. The effect of research variables on CSA

As depicted in Table 1, supporting institutions (β=0.113; t-value=2.026) would have a significant and positive effect on CSA. With 99% confidence at 0.001, the study hypothesis was therefore verified. The supporting institutions' sub-sectors analysis showed that according to agricultural experts, the support of governmental and non-governmental institutes such as the Ministry of Agriculture Jihad and the Environment Organization in identifying farmers' needs through their direct participation in implementing climate-smart farming methods (β=0.849; t-value=44.324) was of great significance (Table 2).

Investment (β=0.137; t-value=2.939) had a favorable and substantial influence on CSA techniques, according to the data given in Table 1. Therefore, it can be stated that the research hypothesis was confirmed at 0.001. Moreover, the investment subsections analysis indicated that the most important component was related to “the new facilities and technologies import (β=0.787; t-value=32.127) and would have a significant impact on CSA (Table 2).

As presented in Table 1 and considering the fact that the t-value=1.430 is less than 1.96 and β = 0.084, it can be said that the research hypothesis, according to which information and knowledge have a positive and significant effect on the CSA acceptance, is not acceptable. The results of Table 1 show that the effect of innovation on CSA has t-value=3.751 and β=0.227. Therefore, it can be said that with a 99% probability, the null hypothesis is rejected, and the research hypothesis is confirmed at the significance level of 0.001. In addition, when analyzing the impact of innovation sub-sectors on the CSA acceptance, it was found that innovation in the production of seeds adapted to CC with higher performance, higher quality, earlier treatment, and higher adaptation toward climates and climate stresses (β=0.777; t-value=31.598) would have a significant impact on CSA (Table 2).

According to the research findings, agricultural products insurance with β=0.041 and t-value=1.009 had no impact on CSA acceptance. As a result, the research hypothesis about the large and favorable impact of agricultural and horticultural product insurance on CSA is disproved (Table 1). According to the research findings, ACC (β=0.405; t-value=6.852) as a mediating variable has a substantial and positive impact on food security (Table 1). With 99% confidence and a significance level of 0.001, the research's conclusion that ACC has a positive and significant impact on food security is confirmed. In addition, the most essential components of ACC, according to the findings, were integrated nutrient and soil management (β=0.746; t-value=24.216); the use of conservation farming methods (β=0.723; t-value=19.584); and the improvement of planting, growing, and harvesting techniques (β=0.714; t-value=19.106) (Table 2).

As shown in Table 1, the significance path coefficients between CSA variables (β=0.522; t-value=8.498), ACC (β=0.805; t-value=26.671), and food security (β=0.405; t-value=6.852) are higher than 1.96, at the 99% dependability level, demonstrating the significant impact of CSA on food security as well as the indirect effects of CSA via the mediating factor of ACC.

[Insert Table 1]

[Insert Table 2]

4.3. Assessing the impact of climate change on food security components

This section examines the effects of CC on four essential elements of food security (availability, stability, sustainability, and usefulness). The results showed that sustainability with t-value=127.552 and β=0.958 was the most important component of food security that would be affected by CC. Furthermore, the analysis of the sub-sections of this component shows that the important assets of farmers and gardeners (land, financial capital, and credits) with β=0.764 and t-value=24.903 were the most important sub-components of sustainability that were affected by CC (Table 3).

Food accessibility with β=0.875 and t-value=59.590 was the next important component that would be influenced by CC. The most important sub-component that would have the greatest impact on food accessibility was the increase in the purchasing power of farmers by increasing the income from their horticultural and agricultural crops sale (β=0.753; t-value=23.954). According to the research results, the usability component with β=0.886 and t-value=55.864 ranked next. In addition, the findings indicated that the most crucial sub-component of food usability among rural households was food security status with β=0.764 and t-value=24.903 (Table 3).

According to the results, the component of food availability (β=0.802; t-value=33.460) was the least important factor. However, according to agricultural experts, the most important sub-components affecting the availability of food were the attendance of farmers and gardeners at training-extension classes formed by extension agents and experts on mitigation CC and ACC (β=0.750; t-value=22.506) (Table 3).

[Insert Table 3]

4.4. Determining the significance of the mediating variable impact

Following an examination of CSA's direct and indirect effects on food security, it is time to look at how strong these effects are. The evaluation of the standardized path coefficients between CSA and food security (β=0.552) indicates that CSA directly explains 55% of the changes in food security. In other words, the two coefficients (β=0.805 and β=0.405) also showed that the CSA has an indirect influence on food security and through ACC, with a value of 0.32%. In the following equation, the z-value of the Sobel test was equal to 6.79, and since the value is higher than 1.96, at a 99% confidence level, it can be concluded that the mediating influence of ACC on the connection between CSA and food security is considerable (z-value=$\frac{0.326}{0.048} = 6.79$).

4.5. Determining the model's goodness of fit quality

Using the divergent validity criterion, the model's goodness of fit is assessed. If a structure in the model interacts with its indicators more frequently than other structures, or if the model has an appropriate goodness of fit, this is known as acceptable divergent validity. For this purpose, the GOF criterion was used to check the fitness of the model. When the GOF value for an endogenous structure is between 0.02, 0.15, and 0.35, the model has moderate predictive power, excellent predictive strength, and outstanding predictive ability, respectively (Goldbach et al., 2017;

Nikolopoulou, 2023). Given that the GOF score is 0.636, the model's quality and predictive ability are both excellent and extremely strong.

5. Discussion

5.1. Investigating the CSA components' impact on ACC

According to the results, innovative technologies developed by the CSA have the potential to address climate-related issues. In the agriculture sector, however, limited use of these technologies remains an issue. As a result, CC poses a complex danger to agricultural output and food security in developing nations like Iran, necessitating ecologically friendly solutions. Therefore, the use of seeds resistant to CC; the use of rather-ripe cultivars, storage technologies, and water conservation; the use of conservation farming methods; and the modernization of capacities for predicting climate crisis serve as the most appropriate technologies for CSA in the current climate of northern Iran, particularly for small-scale farmers. The high initial investment costs, higher labor needs, and high maintenance intensity associated with conservation agriculture and rainwater storage are also factors to consider and may pose challenges to Iran's adoption of innovation. In this regard, provided the necessary measures are applied to accelerate the adoption of the aforementioned innovations, the farmers' resilience in the agriculture sector will increase to some extent in response to CC challenges, and agricultural production and food security will also improve. This conclusion aligns with the findings reported by Khatri-Chhetri et al. (2017). They argued that activities in the context of CSA should include capacity building for new technology and structural partnerships. These technologies must be appropriate and adapted to local conditions. According to Senyolo et al. (2018) and Long et al. (2016), adopting and disseminating technology breakthroughs for the adoption of CSA methodologies, as well as other initiatives, play a critical role in achieving sustainability.

The findings of the current study indicate that the level of investment in the agricultural sector significantly influences farmers' adoption of CSA practices. Access to adequate agricultural finance in developing countries like Iran, on the other hand, has been a difficulty for decades. This is due to the modest proportion of agriculture in financial institutions' investment portfolios, especially when compared to the proportion of agriculture in gross domestic product (GDP). Access to adequate agricultural finance in developing countries such as Iran has been a difficulty for decades. Activities that are supported by the government can have a catalytic impact. It can help to shift CC mitigation and adaptation budgeting to larger sources of agricultural budgeting, such as domestic government spending and agricultural investment by manufacturers. Increasing investment is necessary to reduce risk and improve key flexibility in empowering stakeholders and smallholder farmers who are more financially vulnerable. These manufacturers will require assistance during the shift to new systems, and more investment can help to facilitate this change. Amadu et al. (2020) claim that the danger of food insecurity as a result of CC is increased in many low- and middle-income countries due to resource restrictions. As a result, CSA policies and financial flows in low-income areas have the potential to significantly affect food security by boosting crop productivity in the face of rising weather unpredictability and severe weather shocks.

The next component affecting the adoption of CSA is the role of supporting institutions. At the local, national, and international levels, coordinated policies, institutions, and resources are needed to scale and reform the CSA in order to affect beneficial changes in agricultural output and food systems. Innovative ways to build and strengthen formal and informal institutions, as well as assistance for livelihood diversification techniques and coping mechanisms, may be required to achieve this. The results of the study conducted by Totin et al. (2018) demonstrated that institutional dimensions (institutions and supporting agencies) are important because they had political representations, historical contingencies, and local power-specific dynamics that also played an important role in approving and scaling CSA options.

The results of this study show that according to agricultural experts, farmers are often aware of CC and CSA methods. They believe that farmers need more access to new technologies, financial resources, and support to invest in CSA than acquiring knowledge and information. However, according to other researchers such as Nyasimi et al. (2017) and Westermann et al. (2018), one of the main limitations regarding the widespread acceptance of CSA was related to the flow of knowledge and information. Nyasimi et al. (2017) and Westermann et al. (2018) showed that while there is information available on various CSA options, particularly those designed for local conditions, it is often insufficient. Inadequate knowledge, for example, increases the danger of sowing expensive seeds that may not survive or may provide low harvests (Asfaw et al., 2014; Asfaw et al., 2016). As a result, the information available to producers about CSA options that are well-suited to their conditions will be an important factor in adaptation. Information can originate from a variety of locations, including government extension programs, non-governmental groups, and donor-funded projects. Despite the study's findings and extensive data, seasonal climate fluctuation has a significant impact on producers' risks. It is logical to assume that knowledge management is the foundation for developing adaptive capability in rural communities. Increasing access to reliable information is important to facilitate adaptation because it can improve farmers' decision-making skills based on their farming methods. The results of this study contradict the importance of the role of agricultural insurance policies in the adoption of CSA methods since adopting CSA practices requires producers to make more investments.

The extent to which farmers can implement major adjustments depends largely on the availability of insurance policies that facilitate their access to credit and services (Ghosh et al., 2021). Since most farmers lack insurance and must learn new agricultural techniques, CSA practices could be seen as a risky investment, just like any new technique or technology. Furthermore, credit limitations influence insurance uptake, particularly when the initial investment expenditures are high; the benefits of these techniques are frequently only seen after a few years. This suggests that, in the near run, monetary constraints and land opportunity costs are likely to impact producers' decisions to utilize CSA methods. (Asfaw & Maggio, 2016; FAO et al., 2017).

5.2. Investigating the effect of CSA on food security

As shown in Table 1, CSA influences food security in two ways. One impact is due to CSA's direct, positive, and substantial influence on food security, while the other is related to CSA's indirect effect on food security via the mediating variable of ACC. This demonstrates that there is a need to strengthen comprehensive policies, strong and sustainable financial institutions at the local, national, and international levels to create a favorable environment for the transformation of agricultural production systems towards CSA and to increase the capacity to increase ACC. Accordingly, Hasan et al. (2018) demonstrated that CSA is a feasible plan for boosting food security in a changing environment. They thus have both direct and indirect effects on one another. Increased involvement in these issues adds to the limited options already available to many poor households suffering from food insecurity. It is often caused by high production risk, a lack of insurance and financing, or a lack of touch with dynamic incoming and outgoing markets. Therefore, more public, and private funding will be required to assist low-income households in switching to CC. Direct investments in agricultural production, such as the development of modified crops that are better suited to the CC, are one example.

Investments that are often made to improve performance-supporting physical infrastructure and markets. The efficient utilization of natural resources and other agricultural resources is one of the key elements of CSA. In order to equip agricultural communities to deal with the uncertainty caused by CC, it is also important to be robust to the dangers connected with it. To this aim, measures to enhance efficiency and flexibility on a variety of scales should be addressed, as well as the environmental, economic, and social elements of sustainability. It is recommended that in CSA approaches, more emphasis be placed on integrated nutrient and soil management methods, conservation agriculture, improved planting, growing, and harvesting techniques, optimal land use management, utilization of various types, and strains suited to CC. Additionally, integrated pest, disease, and weed control must be used by farmers as well as government organizations and decision-makers. Therefore, food security requires a long-term reform of the agricultural sector, and reconfiguring CC responses is critical to attaining this goal. These findings are consistent with those of Hasan et al. (2018), Venkatramanan & Shah (2019), and Brouziyne et al. (2018) and have been validated by them who have stated that ACC is essential to achieve food security.

5.3. Investigating the effect of ACC and CSA on food security components

According to the findings of this study, food security's most essential component is sustainability, which will be badly harmed by climate disasters. CC has an impact on the sustainability of food resources by influencing production. Climate shocks can have an impact on individuals who are not poor but are vulnerable. Therefore, these shocks can lead to poverty (Goli et al., 2020).

These catastrophes can wipe away decades of hard work and asset accumulation, causing irreversible harm to people's health and livelihoods, particularly smallholder farmers. As shown in FAO (2016) reports, the goals of sustainable development require more sustainable food systems. In order to maximize productivity and production, sustainably manage resources, protect ecosystems, develop capacity for CC adaptation, and gradually improve soil and soil quality are all necessary when implementing CSA approaches. The long-term sustainability of both natural and human systems depends on responsible and effective governance, which includes the creation of uniform policies and strategies across industries, the synchronization of investments and legal frameworks, and the development of the capacity of pertinent institutions and stakeholders at all levels. This is based on the sharing of ideas among stakeholders and collaborations and the use of processes to achieve consensus on sustainable development goals. CSA is an important component of a sustainable food and agriculture strategy, which aims to promote sustainable agriculture at three levels of sustainability, with a special focus on CC. Accordingly, CSA is also considered one of the main elements in achieving sustainability. In some areas with significant levels of food poverty, Dwivedi et al. (2017) found that CC was likely to reduce agricultural output, production stability, and income. Therefore, the development of CSA is crucial for achieving future food security. Finally, according to the results, the structural model of this study is shown in Fig. 3. This diagram depicts a causal relationship (in the form of a path analysis). It is evident that food security is directly influenced by ACC and indirectly influenced by CSA. Moreover, the variables F-AVA, F-COU, F-ACE, and FS-SUS have a direct and substantial impact on food security. CSA is directly impacted by the variables Sup-CSA, Inn-CSA, and Inv-CSA.

[Insert Figure 3]

In assessing the impact of CC on food security, it is necessary to pay attention to the four basic foundations of food security (i.e. availability, access, utilization and stability). Availability refers to a continuous and sufficient supply of food to meet nutritional needs, while access includes the physical and economic ability to obtain food. Utilization includes the appropriate use of food at the individual level to ensure adequate nutrition, and stability refers to the flexibility and predictability of food systems in handling disturbances and maintaining continuous access to nutritious food. Focusing on these components, can make a deep understanding of how CC affects components of food security beyond sustainability can be gained.

5.4. Research limitations

Like any other study, this research has its limitations. One significant limitation of this study is that it only focused on analyzing the attitudes of agricultural experts. Moreover, it aimed to exclusively explore the study's objectives using a quantitative approach which is appropriate for discovering significant patterns in the data but fails to adequately support potential causal mechanisms. The findings of the present study will serve as the foundation for our forthcoming research, which will examine the role of CSA in farmers' ACC and food security. This subsequent study will employ a mixed-methods approach, combining qualitative and quantitative techniques for a comprehensive analysis. Another limitation of the study was its incapability to specify the experts' participation threshold in supporting CSA in farming systems. This is because the use of locally generated coefficients may be more suited for comprehensive research examining the possible effects of farming operations on food security outcomes and CSA.

The study's findings suggest some strategies that governments and policymakers can employ to boost food security and CSA usage under CC conditions as follows:

- Creating and executing training programs for farmers to increase their capability, based on CSA methods and principles.
- Increasing the amount of money available as subsidies, incentives, or support for farms to implement CSA methods (such as tax credits for CSA technology purchases and low-interest loan availability).
- Promoting collaborations for technology transfer and exhibiting living labs to entice farmers to embrace cutting-edge technologies.
- Increasing the number of laws and regulatory frameworks that support CSA efforts and prioritize them at the national and local levels in order to encourage CSA practices.
- Increasing the social capital of farmers and organizations-like farmer cooperatives and extension services-that aid in the implementation of CSA.

Creating insurance programs specifically designed to shield CSA producers from weather-related hazards.

6. Conclusion and policy implications

CC is becoming a danger to sustainable development. The ability of the agricultural industry to feed the world and attempts to eradicate hunger, malnutrition, and poverty may be threatened by the expected CC consequences. This study was carried out to better understand how CSA components contribute to ensuring food security. The results showed that innovation, investment, and supporting institutions were the most important components of CSA which played the most important role in adapting to CC and achieving food security.

The first policy implication of the findings is that agricultural sectors must be ready in order to quickly alter the environment, adopt new technology, enhance public and private institution investment, and give greater government support for CSA approaches. Second, reducing emissions in agriculture is critical, as the agricultural sector contributes to the accumulation of GHG, which leads to CC. Agriculture and food security throughout the world are confronted with significant problems even without CC. The demand for food and other agricultural products has increased in the majority of developing countries due to population growth and growing wages. It will be difficult for many low-income countries, especially emerging nations like Iran, to secure adequate food for everyone without further efforts to boost agricultural output and decrease poverty. Third, considerable changes in agricultural production and food systems are necessary to address the interconnected problems of achieving sustainability, preserving food security, and reducing CC. As a result, boosting resource efficiency appears to be critical for enhancing and protecting food security in the long run, as well as making a substantial contribution to decreasing CC. The study's findings indicate that CSA offers a framework for enacting all-inclusive policies, suitable institutions, and superior governance in order to realize sustainable and climate-sensitive development plans.

The findings of this study can be utilized to direct additional financing to fulfill the investment needs of research organizations, as well as to assist farmers in overcoming barriers to using CSA methods, such as prepayment expenses and temporary income loss. Responses appear to need activation in the short, medium, and long term. Some medium- and long-term solutions demand quick thinking, planning, and capital investment. Investments in sectors such as forestry, livestock breeding, seed propagation, research and development, innovation, and information sharing, for example, can be considered to increase adaptation. As a result, the world must take steps and appropriate measures to eradicate hunger and malnutrition. The CSA technique aids farmers in developing nations that are susceptible to food insecurity due to CC, have few finances, little government assistance, and few inputs to adapt to changes. Action is needed to support those producers who are most impacted by CC but have received the least help and support, according to the movement for climate justice. Additionally, it enables developing nations to accelerate their economic growth and enhance their food security. Promoting food security and helping farmers adjust to change may frequently have significant benefits for mitigation. Finding the best approach to establish incentives to encourage people to choose climate-smart solutions is the key goal. Agricultural policies are intricately related to support for the rural economy in many countries. Low-income countries require additional infrastructure to direct production to more sustainable and productive paths. Therefore, research and development (R&D) partners are essential in creating and advancing CSA practices that enhance rural communities, boost smallholder livelihoods and employment, and lessen unfavorable social and cultural effects including forced migration and land loss. Many poor countries can greatly enhance the planning and execution of their crop protection programs.

The fact that the only empirical evidence for the proposed theory comes from the results of this study is one of the inherent limitations of a conceptual analysis like the one offered here. Therefore, it will be essential and helpful to evaluate the proposed links and structures in further experimental research. In addition to the factors examined in this study, several mediating factors, such as gender, predisposition to behavior, attitude, desire and determination in maintenance, and sustainability upon the occurrence of CC-related adaption behavior, can be significant. Therefore, it is suggested that in future studies, the mediation effects of these variables be investigated. While this study empirically focused on Mazandaran Province, Iran, the methods and results are applicable to other rural regions in the developing world.

List of abbreviations:

CSA: Climate-smart agriculture

CC: Climate change

ACC: Adaptation to climate change

IPCC: According to the Intergovernmental Panel on Climate Change

GDP: Gross domestic product

R&D: Research and development

Funding: This study received no funding from any organizations.

Conflicts of interest/Competing interests: We have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and material: We confirm that the data, models, or methodology used in the research are proprietary, and derived data supporting the findings of this study are available from the first author on request.

Ethic approval: In conducting the research and administering the questionnaire, we strictly adhered to all ethical standards, ensuring that the data collected and analyzed from respondents was respectful and in compliance with all applicable guidelines.

References

Abegunde, V.O., Sibanda, M., & Obi, A. (2019). The Dynamics of Climate Change Adaptation in Sub-Saharan Africa: A Review of Climate-Smart Agriculture among Small-Scale Farmers. Climate, 7, 132.

Akbari, A., Mirnasl, N., & Hipel, K.W. (2021). Will peaceful waters flow again? A game-theoretic insight into a tripartite environmental conflict in the Middle East. Environ Manage, 67, 667-681.

Ali, E. (2021). Farm households' adoption of climate-smart practices in subsistence agriculture: evidence from northern Togo. Environ Manage, 67(5), 949-962.

Ali, A., & Erenstein, O. (2017). Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. Climate Risk Manage, 16, 183-194.

Amadu, F.O., McNamara, P.E., & Miller, D.C. (2020). Yield effects of climate-smart agriculture aid investment in southern Malawi. Food Policy, 92, e101869.

Ardakani, Z., Bartolini, F., & Brunori, G. (2017). Food and Nutrition Security in Iran: Application of TOPSIS Technique. New Medit, 16(1), 18-28.

Asfaw, S., & Maggio, G. (2016). Gender Integration into Climate-Smart Agriculture (CSA): Tools for Data Collection and Analysis for Policy and Research. Background Paper Prepared for the Source Book on Gender in CSA, Washington DC (also published as FAO publication).

Asfaw, S., Maggio, G., & Lipper, L. (2016). Gender, Climate shock and Welfare: Evidence from Malawi. J of Dev Stud, 53 (7), 1-21.

Asfaw, S., Di Battista, F., & Lipper, L. (2014). Food Security Impact of Agricultural Technology Adoption under Climate Change: Micro-evidence from Niger. J of African Econ, 25(5).

Atamaleki, A., Sadani, M., Raoofi, A., Miri, A., Bajestani, S. G., Fakhri, Y., & Khaneghah, A. M. (2020). The concentration of potentially toxic elements (PTEs) in eggs: a global systematic review, meta-analysis and probabilistic health risk assessment. Trends in Food Sci & Technol, 95, 1-9.

Brouziyne, Y., Abouabdillah, A., Hirich, A., Bouabid, R., Zaaboul, R., & Benaabidate, L. (2018). Modeling sustainable adaptation strategies toward a climate-smart agriculture in a Mediterranean watershed under projected climate change scenarios. Agri Sys, 162, 154-163.

Daneshvar, M.R.M., Ebrahimi, M., & Nejadsoleymani, H. (2019). An overview of climate change in Iran: facts and statistics. Environ Sys Res, 8(1), 1-10.

Dwivedi, A., Naresh, R.K., Kumar, R., Kumar, P., & Kumar, R. (2017). Climate smart agriculture. Pro Agri-Hort Tech Innovat, 20-42.

Fahad, Sh., & Wang, J. (2018). Farmers' risk perception, vulnerability, and adaptation to climate change in rural Pakistan. Land Use Policy, 79, 301-309.

FAO (Food and Agriculture Organization) of the United Nations. (2010). Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation. FAO, Rome, Italy.

FAO. (2013). Financing Climate-smart Agriculture 375–406 (Climate-Smart Agriculture Sourcebook Module 14, FAO.

FAO, IFAD, UNICEF, WFP, & WHO. (2017). The State of Food Security and Nutrition in the World 2017. Building resilience for peace and food security. Rome.

Fuss, S., Havlík, P., Szolgayová, J., Schmid, E., Reuter, W. H., Khabarov, N., & Kraxner, F. (2015). Global food security & adaptation under crop yield volatility. Technol Forecast and Soc Change, 98, 223-233.

Goldbach, J.T., Schrager, S.M., & Mamey, M.R. (2017). Criterion and Divergent Validity of the Sexual Minority Adolescent Stress Inventory. Frontiers in Psychol, 8, 2057.

Ghosh, R. K., Gupta, S., Singh, V., & Ward, P. S. (2021). Demand for crop insurance in developing countries: New evidence from India. J of Agri Econ, 72(1), 293-320.

Goli, I., Omidi Najafabadi, M., & Lashgarara, F. (2020). Where are We Standing and Where Should We Be Going? Gender and Climate Change Adaptation Behavior. J of Agri Environ Ethics, 33(2).

Hasan, M.K., Desiere, S., D'Haese, M., & et al. (2018). Impact of climate-smart agriculture adoption on the food security of coastal farmers in Bangladesh. Food Sec, 10, 1073–1088.

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. Environ Sci Policy, 127, 311-320.

IPCC. (2019). Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. (In press)

International Food Policy Research Institute (IFPRI). (2020). Global Food Policy Report: Building Inclusive Food Systems. Washington, DC: International Food Policy Research Institute. https://doi.org/10.2499/9780896293670F

Iranian Ministry of Jihad Agriculture. (2020). Available on: https://irandataportal.syr.edu/ministry-of-agriculture.

Iran Statistics Center. (2018). Iran Statistics Center website. Available on: https://www.amar.org.ir/english

Karandish, F., & Hoekstra, A.Y. (2017). Informing National Food and Water Security Policy through Water Footprint Assessment: The Case of Iran. Water, 9(831), 1-25.

Katsini, L., Bhonsale, S., Akkermans, S., Roufou, S., Griffin, S., Valdramidis, V., & Van Impe, J. F. (2022). Quantitative methods to predict the effect of climate change on microbial food safety: A needs analysis. Trends in Food Sci & Technol, 126, 113-125.

Kavianpoor, A., Barani, H., Sepehry, A., Bahremand, A., & Moradi, H. (2019). Climate change impact on quality of life indicators of pastoralists (case study: Rangelands of Haraz River Basin Mazandaran province, Iran). J of Rangeland Sci, 9(1), 24-39.

Khatri-Chhetri, A., Regmi, P.P., Chanana, N., & Aggarwal, P.K. (2020). Potential of climate-smart agriculture in reducing women farmers' drudgery in high climatic risk areas. Clim Change, 158(1), 29-42.

Khatri-Chhetri, A., Pant, A., Aggarwal, P.K., Vasireddy, V.V., & Yadav, A. (2019). Stakeholders prioritization of climate-smart agriculture interventions: Evaluation of a framework. Agri Sys, 174, 23-31.

Khatri-Chhetri, A., Poudel, B., & Shirsath, P.B. (2017). Assessment of Climate-Smart Agriculture (CSA) Options in Nepal. https://www.researchgate.net/publication/326847389

Lipper, L., & Zilberman, D. (2017). A short history of the evolution of the climate smart agriculture approach and its links to climate change and sustainable agriculture debates. In: Lipper, McCarthy, Zilberman, Asfaw and Branca (eds.). Climate smart agriculture: building resilience to climate change. Springer, USA.

Long, T.B., Blok, V., & Poldner, K. (2016). Business models for maximising the diffusion of technological innovations for climate-smart agriculture. Int Food and Agribus Manage Rev, 20(1), 5-23.

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

Long, T.B., Blok, V., & Coninx, I. (2019). The diffusion of climate-smart agricultural innovations: Systems level factors that inhibit sustainable entrepreneurial action. J of Clean Prod, 232, 993-1004.

Lu, S., Bai, X., Li, W., & Wang, N. (2019). Impacts of climate change on water resources and grain production. Technol Forecast and Soc Change, 143, 76-84.

Mazandaran Agricultural Jihad Organization. (2020). https://jkmaz.ir/En/HomeEn

Mazandaran Meteorological Organization. (2018). http://www.mazmet.ir/index.php/en/

Meinzen-Dick, R., Bernier, Q., & Haglund, E. (2013). The six "ins" of climate-smart agriculture: Inclusive institutions for information, innovation, investment, and insurance. CAPRi Working Paper No.114. Washington, DC. International Food Policy Research Institute. http://dx.doi.org/ 10.2499/CAPRiWP114.

Meteorological Department of Mazandaran Province. (2019). https://irandataportal.syr.edu/iran-meteorological-organization

Ministry of Agriculture Jihad. (2020). Available on: https://irandataportal.syr.edu/ministry-of-agriculture.

Modarres, R., Sarhadi, A., & Burn, D.H. (2016). Changes of extreme drought and flood events in Iran. Global and Plan Change, 144, 67-81.

Moradi, R., Koocheki, A., Nassiri Mahallati, M., & Mansoori, H. (2013). Adaptation strategies for maize cultivation under climate change in Iran: irrigation and planting date management. Mitig Adapt Strateg Glob Change, 18, 265-284.

Nikolopoulou, K. (2023). What Is Discriminant Validity? | Definition & Example. Scribbr. Retrieved January 15, 2024, Available at: https://www.scribbr.com/methodology/discriminant-validity/

Nyasimi, M., Kimeli, P., Sayula, G., Radeny, M., Kinyangi, J., & Mungai, C. (2017). Adoption and Dissemination Pathways for Climate-Smart Agriculture Technologies and Practices for Climate-Resilient Livelihoods in Lushoto, Northeast Tanzania. Climate, 5, 63.

Partey, S.T., Zougmoré, R.B., Ouédraogo, M., & Campbell, B.M. (2018). Developing climate-smart agriculture to face climate variability in West Africa: Challenges and lessons learnt. J of Clean Prod, 187, 285-295.

Plunge, S., Gudas, M., Povilaitis, A., & Piniewski, M. (2022). Evaluation of the costs of agricultural diffuse water pollution abatement in the context of Lithuania's water protection goals and climate change. Environ Manage, 1-18.

Saj, S., Torquebiau, E., Hainzelin, E., Pages, J., & Maraux, F. (2017). The way forward: An agroecological perspective for Climate-Smart Agriculture. Agri Eco Environ, 250, 20-24.

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? J of Clean Prod, 172, 3825-3840.

Thornton, P.K., Ericksen, P.J., Herrero, M., & Challinor, A.J. (2014). Climate variability and vulnerability to climate change: a review. Global Change Biol. http://dx.doi.org/10.1111/gcb.12581.

Totin, E., Segnon, A.C., Schut, M., Affognon, H., Zougmoré, R.B., Rosenstock, T., & Thornton, P.K. (2018). Institutional Perspectives of Climate-Smart Agriculture: A Systematic Literature Review. Sustain, 10. 1990.

Vallejo, G., Ato, M., Fernández, M.P., & Livacic-Rojas, P.E. (2019). Sample size estimation for heterogeneous growth curve models with attrition. Behavr Res Meth, 51(3), 1216-1243.

Venkatramanan, V., & Shah, S. (2019). Climate Smart Agriculture Technologies for Environmental Management: The Intersection of Sustainability, Resilience, Wellbeing and Development. In: Shah, S., Venkatramanan, V., & Prasad, R., eds. Sustainable Green Technologies for Environmental Management. Springer, Singapore. https://doi.org/10.1007/978-981-13-2772-8_2

Westermann, O., Förch, W., Thornton, Ph., Körner, J., Cramer, L., & Campbell, B. (2018). Scaling up agricultural interventions: Case studies of climate-smart agriculture. Agri Syste, 165, 283-293.

Zougmore, R.B., Partey, S.T., Ouedraogo, M., Torquebiau, E., & Campbell, B.M. (2018). Facing climate variability in sub-Saharan Africa: analysis of climate-smart agriculture opportunities to manage climate-related risks. Cahiers Agri, 27(3).

Appendix 1

A1 Google Scholar results on climate smart agriculture and food security

Researcher	Title
Lipper et al. (2014)	Climate-smart agriculture for food security
Hasan et al. (2018)	Impact of climate-smart agriculture adoption on the food security of coastal farmers in Bangladesh
Zougmore et al. (2018).	Facing climate variability in sub-Saharan Africa: analysis of climate-smart agriculture opportunities to manage climate-related risks
Zaman et al. (2021)	Climate-Smart Agriculture Practices for Mitigating Greenhouse Gas Emissions.
Wassmann et al. (2019)	Adaptation, mitigation and food security: Multi-criteria ranking system for climate-smart agriculture technologies illustrated for rainfed rice in Laos
Guthman et al. (2006)	Squaring farm security and food security in two types of alternative food institutions
Kifle (2021)	Climate-Smart Agricultural (CSA) practices and its implications to food security in Siyadebrina Wayu District, Ethiopia
Abegunde and Sibanda (2018)	Agricultural sustainability and food security in the 21st century: A review of Climate-Smart Agriculture (CSA) in Africa
Lopez-Ridaura et al. (2018)	Climate smart agriculture, farm household typologies and food security: an ex-ante assessment from Eastern India
Duffy et al. (2017)	National level indicators for gender, poverty, food security, nutrition and health in Climate-Smart Agriculture (CSA) activities
Wekesa et al. (2018)	Effect of climate-smart agricultural practices on household food security in smallholder production systems: micro-level evidence from Kenya
Ku and Yan (2018)	he food security crisis and CSA movement in China: Green social work practice in Yunnan province
Ghosh (2019)	Climate-smart agriculture, productivity and food security in India
Anuga et al. (2019)	Determinants of Climate Smart Agriculture (CSA) Adoption among Smallholder Food Crop Farmers in the Techiman Municipality, Ghana
Mutenje et al. (2019)	Promoting climate smart agriculture in Malawi for sustainable food security
Submitter et al. (2021)	Impact of climate smart agriculture on food security: an agent-based analysis

Appendix 2: Questionnaire

Code	

With regards Dear experts, as you know, among the priorities of each country's development goals, achieving food security is of particular importance. The truth is that climate-smart agriculture is one of the basic requirements for achieving food security. It should be said that climate-smart agriculture integrates three dimensions of sustainable development (economic, social and environmental) by addressing the issue of food security and climate challenges, and consists of three main elements:

- Sustainable increase in yield and income in the agricultural sector;
- Adapting and creating flexibility against climate changes;
- Reducing or eliminating the emission of greenhouse gases (if possible).

Therefore, the questionnaire at your disposal has been designed for “the importance of using climate-smart agriculture in order to improve food security from the point of view of the experts of the Agricultural Organization of Mazandaran Province”.

For sure, your accurate answers in completing the questionnaire will give the exact points that represent your point of view on this topic. It is necessary to remember that the information obtained from the questionnaire will remain with the researcher and will not be used for any other purpose except for statistical use in this research. Thank you in advance for your cooperation.

Dear expert, this section is designed to measure your attitude towards climate-smart agriculture. Please mark your point of view with √.
1=Very high; 2= High; 3=Medium; 4= Low; and 5 = Very low

	Row	Items	1	2	3	4	5
Attitude towards smart climate agriculture (CSA)	1	Climate-smart agriculture helps to produce more sustainable products by using less land, water, and inputs.					
	2	The growth of greenhouse gas emissions can have serious consequences for biodiversity and ecosystem services, soil and land protection.					
	3	Climate agriculture paths, by using new solutions to adapt to climate changes, have a great role in improving the performance of gardeners (adaptive methods have dramatic effects in the control of immediate climate crises).					
	4	Farmers have an effective role in reducing the emission of greenhouse gases (the agricultural sector is one of the main producers of greenhouse gases and as a result of the gradual increase in the global temperature).					
	5	Climatic risks, due to the increase of production risks, challenge the farmer's ability.					
	6	Awareness of the future climate situation (meteorological forecasts) has a great role in predicting the amount of production and providing protection measures against sudden climate changes.					
	7	New technologies (satellites, internet, etc.) are powerful tools for predicting rainfall, glaciers, droughts, storms, etc.					
	8	With the increase of climate changes and as a result the destructive effects that it has on the production of products with traditional production methods, today's agricultural production systems are incapable of providing food security in the long term.					
	9	Severe climatic events in the long-term cause farmers to be exposed to risks and increase uncertainty for investment motives and reduce the effectiveness of innovations in farms and gardens.					
	10	Climate-smart agriculture can reduce threats by increasing the adaptability of agriculture, increasing flexibility and productivity in agricultural production systems.					
	11	Climate-smart agriculture, with a direct effect on the sustainable increase in yield and income, leads to the sustainability of the production of products.					
	12	With the increasing intensity and frequency of climatic events (such as droughts, heavy rains, floods, hail, freezing temperatures, and increasing the maximum temperature), we need this type of agriculture more than ever.					
	13	Climate-smart agriculture shows more flexibility in the face of risks, sudden changes and long-term climate change.					

Dear expert, this section is designed to measure your attitude towards climate-smart agriculture. Please mark your point of view with √.
1=Very high; 2= High; 3=Medium; 4= Low; and 5 = Very low

The components of food security

	Row	Items	1	2	3	4	5
Food availability (F-AVA)	1	How do you evaluate the productivity of agricultural production and the amount of income obtained from the sale of products in relation to the costs incurred?					
	2	To what extent are scientific principles applied in agricultural and horticultural production (natural pesticides, return of agricultural residues, green manure, compost, etc.)?					
	3	How do you evaluate the presence of farmers and gardeners in the educational-promotional classes organized by promoters and experts regarding the protection of crops against climate change?					
	4	To what extent are the points propounded in promotional trainings used in the stages of planting, growing, harvesting and processing agricultural and horticultural products?					
	5	How much is the use of modern protection methods against climate change?					
	6	What is the extent of using scientific principles in the methods of adapting to climate change?					
	7	To what extent are science training classes organized for farmers with smart climate agriculture and adaptation to climate change?					
	8	How do you evaluate the amount of agricultural and garden crops that are destroyed every year due to climate change?					
	9	What is the status of agricultural production resources (water and soil)?					
Food accessibility (F-ACE)	1	How much is the amount of income of farmers and gardeners?					
	2	To what extent will the income obtained from the sale of crops increase the purchasing power of farmers?					
	3	How do you evaluate the quality of the transportation system in terms of transporting agricultural products?					
	4	How much is the allocation of facilities (loans, credits, etc.) allocated to farmers and gardeners to support and increase production?					
	5	To what extent do farmers and gardeners have access to cultivars resistant to climate change?					
	6	What is the economic and physical access of farmers and gardeners to new facilities, technologies and services?					
	7	What is the level of access of farmers and gardeners to the necessary equipment to deal with climate change?					
Food consumption/use (F-COU)	1	How do you evaluate the amount of self-consumption produced by farmers and gardeners?					
	2	What is the health condition of the rural households?					
	3	What is the level of food security in rural households?					
	4	What is the status of educational-promotional programs regarding the use and maintenance of products among villagers?					
	5	What is the level of quality of consumption goods in rural households?					
Food security sustainability (FS-SUS)	1	To what extent do sudden changes in weather (storms, floods, strong winds, sudden cold and heat, cold and frost, etc.) damage agricultural and garden productions?					
	2	What is the level of prevalence of pests and diseases?					
	3	To what extent are biological methods and animal fertilizers used to preserve the sustainability of production resources?					
	4	To what extent can adapting to climate change help better and more production?					
	5	To what extent can the important assets of farmers and gardeners (land and credit) play a role in the sustainability of production?					
	6	To what extent can government support provide the sustainability of food security for future generations?					
	7	To what extent can the use of protection methods guarantee production stability?					

Dear expert, this section is designed to measure your attitude towards climate-smart agriculture. Please mark your point of view with √.
1=Very high; 2= High; 3=Medium; 4= Low; and 5 = Very low

The components of climate-smart agriculture (CSA)

	Row	Items	1	2	3	4	5
Awareness and information	1	Intensity of climate damage on agricultural resources and products.					
	2	Training to plant, grow and harvest the production of genetically modified seeds.					
	3	Teaching and learning adaptation methods through experimental observation using exhibiting farms.					
	4	Real-time awareness of meteorological forecasts and the critical situation of the upcoming weather.					
	5	Increasing the skills and experience of gardeners and farmers in order to carry out the necessary actions during climate tensions.					
	6	Use of resistance cultivars that are compatible with the weather conditions of the region.					
	7	Increasing income through the use of climate-smart agriculture					
	8	Gardeners' and farmers' understanding of the importance of adaptability and flexibility to climate changes in order to increase production and reduce losses					
Insurance of agricultural products against climatic changes	1	Use of agriculture and weather insurance in order to reduce the risk of weather changes.					
	2	Satisfaction with the performance of agricultural products insurance.					
	3	Increasing agricultural insurance facilities to pay part of the insurance fee.					
	4	The extent of the insurances to the commitments.					
	5	Making the expert opinions of insurance experts fairer.					
	6	The rate of receiving compensation from insurances when facing possible losses.					
	7	Financial ability of farmers to pay the insurance fee for agricultural products					
	8	Existence of insurances related to regional weather conditions such as floods, earthquakes, hailstorms, storms, etc.					
	9	The existence of insurance funds supported by the government.					
	10	Applying compulsory insurances in some agricultural products to reduce potential risks.					
Investing in CSA (Inv-CSA)	1	Investing in the establishment of gene banks in order to access desirable and healthy seeds and seedlings.					
	2	Investing in order to identify the real needs of the local people.					
	3	Investing in the production of species resistant to climate change.					
	4	Improving the system of government credits to solve the financial problems and lack of capital of gardeners (low interest loans, crop insurance and production subsidies)					
	5	Investing to provide the desired fertilizer and poison without impurity.					
	6	Investing to import new equipment and technologies.					
	7	Investment to reduce agricultural losses.					
	8	Investing in order to equip gardeners and farmers to adapt and deal with climate change.					
	9	Investing to hold training courses (useful methods of adaptation to climate change, control or fight with climate change, effective use of climate-smart agriculture)					
	10	Investing in the establishment of gene banks in order to access desirable and healthy seeds and seedlings.					

Continue

Dear expert, this section is designed to measure your attitude towards climate-smart agriculture. Please mark your point of view with √.
1=Very high; 2= High; 3=Medium; 4= Low; and 5 = Very low

The components of climate-smart agriculture (CSA)							
	Row	**Items**	1	2	3	4	5
Innovation in CSA (Inn-CSA)	1	Production of compatible seeds (more performance, higher quality, earlier ripening and more compatibility against diseases and weather stress).					
	2	Seedlings and seeds resistant to climatic stresses.					
	3	Technologies of storage and saving water consumption					
	4	Renewing the capacity of meteorological forecasts					
	5	Innovations that alert of weather emergencies					
	6	Creation and development of seed banks in order to provide access to all local producers to the best, locally compatible and suitable products.					
	7	Equipping garden and agricultural systems with new technologies against climate change					
	8	Use of weather-related satellite data for planning future land use.					
	9	Using Nano technologies to increase nutrients and water use efficiency.					
	10	Use of non-conventional energies (use of wind and solar energy to replace conventional energy sources based on fossil fuels).					
	11	Use of biofuels (use of these fuels, especially non-food products and product residues in combination with fossil fuels).					
	12	Use of GPS and GIS in climate forecasts and natural hazards.					
	13	Land and soil mapping using geo-spatial technology.					
	14	Development of risk management technologies					
Supporting institutions in CSA (Sup-CSA)	1	Identification of farmers' needs through their direct participation to implement smart climate agriculture.					
	2	Increasing the motivation of farmers to increase production and reduce waste by using smart climate agriculture.					
	3	Improving access to the appropriate market for inputs (healthy and high-quality inputs without impurities).					
	4	Improving the transportation system.					
	5	Guaranteed sale of products at the real price.					
	6	The use of incentive plans for smart climate agriculture (the one who has the most production with the least damage from climate hazards).					
	7	Attracting the farmer's trust with the government's social support for changing traditional methods to using new methods					
	8	Rational policy making for the allocation of credits and government facilities in adaptation and reduction of climate damage.					
	9	Creating strong links between farmers, researchers, educators, and policy makers and government.					
	10	Optimal land use planning (including the identification of crop cultivation areas using soil, climate and GIS characteristics).					
	11	Improving agricultural extension systems to make departments, employees, farmers smarter, and achieve economic sufficiency.					
	12	Improving and developing risk management.					
	13	Development of cooperative farming methods (farmers in cooperatives can accept new technologies and be more resistant to risks)					
	14	Changing agricultural policies to prepare for natural disasters.					

Dear expert, this section is designed to measure your attitude towards climate-smart agriculture. Please mark your point of view with √. 1=Very high; 2= High; 3=Medium; 4= Low; and 5 = Very low							
	Row	**Items**	1	2	3	4	5
Adaptation to climate change (ACC)	1	Conservation agriculture					
	2	Integrated management of nutrients and soil					
	3	Optimal management of land use change					
	4	Use of diverse varieties and breeds that adapt to climate changes					
	5	Improving the integrated management of pests, diseases and weeds					
	6	Improving the techniques of planting, keeping and harvesting					
	7	Improving the management of water resources					
	8	Building or improving dams in order to flood control					
	9	Genetic modification of plants					
	10	Integration of trees in agricultural systems					
	11	Using effective microbes (increasing soil fertility and productivity)					
	12	Applying organic farming and fertilizer management, including the use of anaerobic decomposers, the use of biological inputs, and avoiding the use of chemical pesticides.					
	13	Using combined and mixed cultivation (planting more than one crop in order to increase productivity and prevent production failure)					
	14	Use of horticulture-agriculture and agriculture-forestry					
	15	Using methods of combining plants, livestock, agroforestry					
	16	Using precision agriculture (precise management of water, nutrients and pests)					
	17	Reduced plow use					
	18	Rehabilitation of degraded lands					
	19	Improving the efficiency of water and nitrogen consumption					
	20	Market management through access to resources and economic equity					
	21	Strategy management, including justice in the distribution of resources and the existence of a supportive government					

Personal Information:

Gender: Female ☐ Male ☐

Education Level: ....

Work Experience : …………… (years)

Table 1

Linear impact of the effects of the research variables to test the general research hypotheses

No.	Research Hypotheses	Path coefficient (β)	(t-value)	Sig. (P-value)	Acceptance/rejection level (0.05)
H_1	Sup-CSA - -► CSA	0.113	2.026	0.001	Confirming the hypothesis
H_2	Inv-CSA - -► CSA	0.137	2.939	0.001	Confirming the hypothesis
H_3	Knowledge and Information- -► CSA	0.084	1.430	0.001	Rejecting the hypothesis
H_4	Inn-CSA - -► CSA	0.227	3.751	0.001	Confirming the hypothesis
H_5	Insurance - -► CSA	0.041	1.009	0.001	Rejecting the hypothesis
H_6	CSA- -► Food security	0.522	8.498	0.001	Confirming the hypothesis
H_7	CSA - -► ACC	0.805	26.671	0.001	Confirming the hypothesis
H_8	ACC - -► Food security	0.405	6.852	0.001	Confirming the hypothesis

Abbreviations:

ACC: Adaptation to climate change
CSA: Climate smart agriculture
Inv-CSA: Investing in CSA
Sup-CSA: Supporting institutions in CSA

Inn-CSA: Innovation in CSA
FS-SUS: Food security sustainability
F-ACE: Food accessibility
F-AVA: Food availability
F-COU: Food consumption/use

Source: Research findings

Table 2
Investigating the effect of components climate smart agriculture on adaptation to climate change

Components	Variable	Path coefficient (β)	(t-value)
Sup-CSA	Identifying the needs of farmers through their direct participation in the implementation of smart climate agriculture	0.849	44.324
	Increasing the motivation of farmers to increase production and reducing production waste by using smart climate agriculture	0.802	26.521
	Improving access to a suitable market for inputs (healthy and high-quality inputs without impurities)	0.779	22.992
Inv-CSA	Investment to import new equipment and technologies	0.787	32.127
	Investment in the distribution of biological and organic fertilizers and toxins	0.718	19.663
	Investment in identifying and meeting the real needs of local people	0.718	18.565
	Upgrading the government credit system to solve financial problems and lack of capital for gardeners (allocation of interest-free or low-interest loans and production subsidies)	0.717	18.425
	Invest in producing species resistant to climate change	0.667	15.279
	Investing in the establishment of gene banks for access to resistant and high-quality seeds and seedlings	0.658	14.486
Inn-CSA	Use of new technologies in seed production with higher yield, higher quality, early ripening, and greater adaptation to diseases and climatic stresses	0.777	31.598
	Use of new technologies in modernizing the capacity of meteorological forecasts	0.753	23.787
	Use of new technologies in water resources management	0.747	22.225
ACC	Integrated nutrient and soil management	0.746	24.216
	Use of conservation farming methods	0.723	19.584
	Improvement of planting, growing, and harvesting techniques	0.714	19.106
	Improving water resources management	0.704	17.385

Abbreviations:
ACC: Adaptation to climate change
CSA: Climate smart agriculture
Inv-CSA: Investing in CSA
Sup-CSA: Supporting institutions in CSA
Inn-CSA: Innovation in CSA
FS-SUS: Food security sustainability
F-ACE: Food accessibility
F-AVA: Food availability
F-COU: Food consumption/use

Source: Research findings

Table 3

The effects of climate change on components of food security

Components	Variable	Path coefficient (β)	(t-value)
FS-SUS	The role of important assets of farmers and gardeners (physical and financial capital) in sustainable production	0.776	26.861
	The role of climate crises (storms, floods, hail, cold, and frost) in the sustainability of crop and horticultural production	0.731	19.490
	The role of using biological control methods and organic fertilizers in maintaining the sustainability of production resources	0.729	18.832
F-ACE	Increasing the purchasing power of farmers by increasing the income from their horticultural and agricultural crops sale	0.753	23.954
	Access to facilities to increase crop and horticultural production	0.749	18.887
	Access to resistant cultivars for climate change	0.706	17.310
F-COU	Food security situation among rural families	0.764	24.903
	The quality of food consumed in the rural household food basket	0.732	17.944
	Health status of rural families	0.712	15.733
F-AVA	Presence of farmers and gardeners in educational-extension classes	0.750	22.506
	Evaluating the productivity of agricultural products and the amount of income from the sale of products to the costs incurred	0.735	19.297
	Application of scientific principles in agricultural and horticultural products (biological pesticides, reuse of environmental wastes, green manure, etc.)	0.730	20.287

Abbreviations:

ACC: Adaptation to climate change
CSA: Climate smart agriculture
Inv-CSA: Investing in CSA
Sup-CSA: Supporting institutions in CSA

Inn-CSA: Innovation in CSA
FS-SUS: Food security sustainability
F-ACE: Food accessibility
F-AVA: Food availability
F-COU: Food consumption/use

Source: Research findings

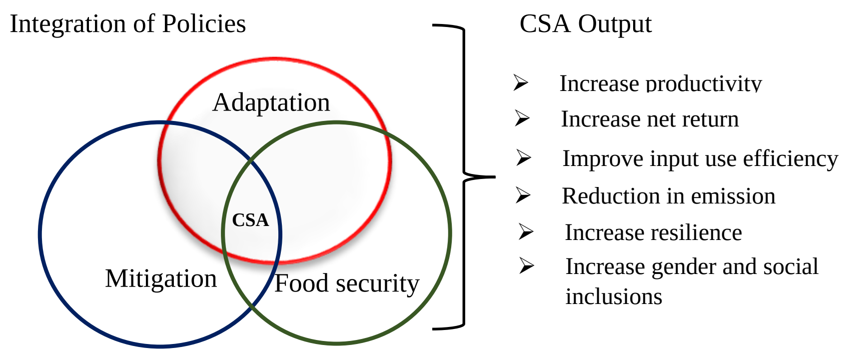


Fig. 1. The conceptual framework for CSA and expected outputs.

Source: Khatri-Chhetri et al. (2017).

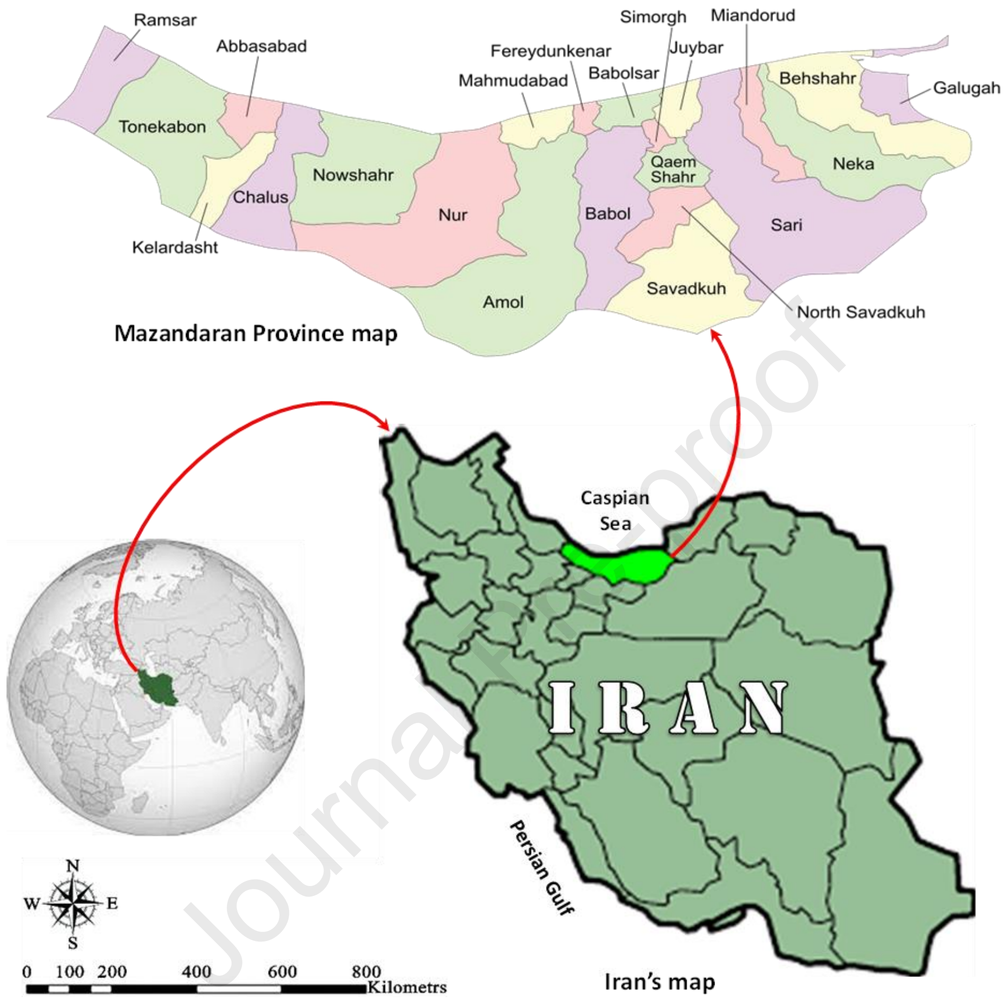


Fig. 2. The geographical location of Mazandaran province.

Source: Authors' own work.

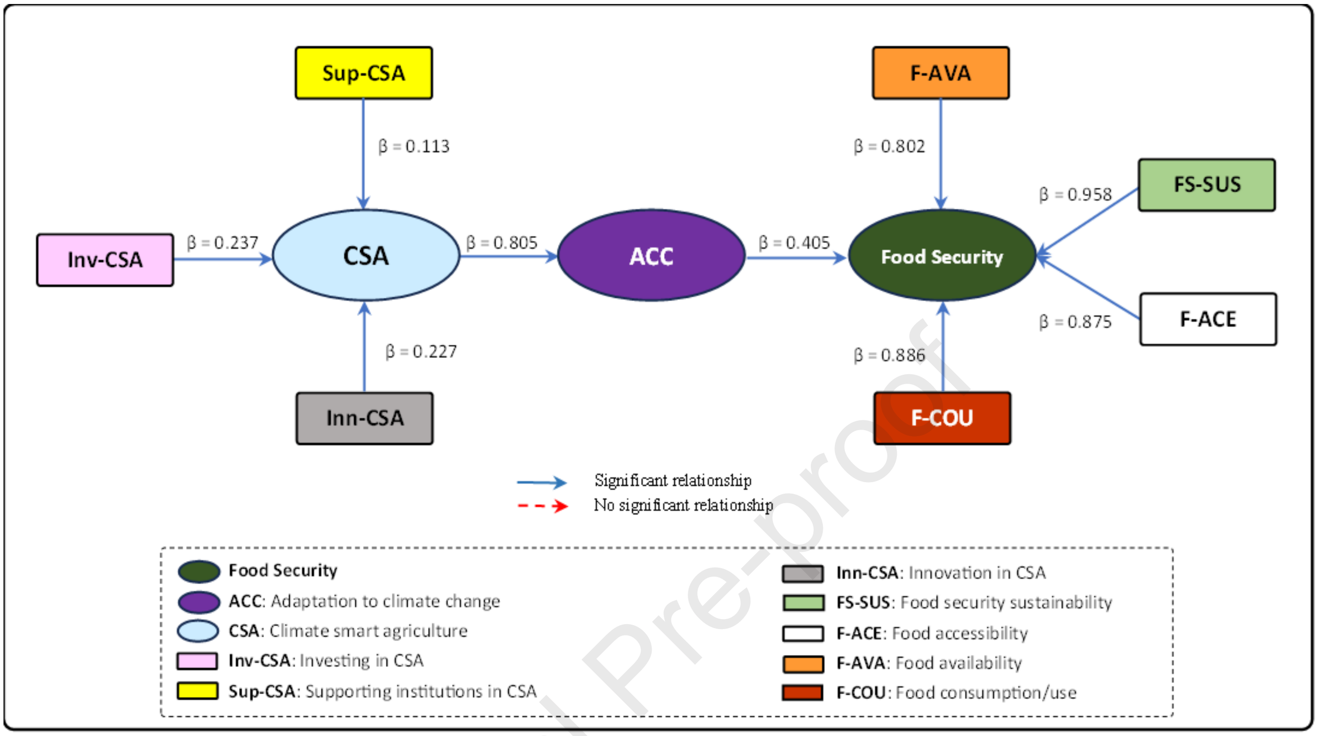


Fig 3. Structural model of the study.

Highlights

- This study aimed to explore the role of climate smart agriculture (CSA) in adaptation to climate change
- Innovation, investment, and supportive institutions would play an important role in accepting CSA
- CSA would be effective in increasing food security through the mediating role of adaptation to climate change
- Responsible and effective governance is critical for the long-term viability of both natural and human systems
- Low-income countries have additional infrastructure to move in a more sustainable direction

Author Contributions Statement:

Conceptualization: I.G., H.A., Z.K.; methodological set up: I.G., P.K., R.Z.; data analysis: I.G., P.K., and S.A.R.; writing of the original draft: I.G.; review and editing: H.A., M.B., D.L-C. All authors have read and agreed to publish this version of manuscript.