International Journal of Advanced Biochemistry Research 2026; SP-10(1): 879-885

International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(1): 879-885
www.biochemjournal.com
Received: 10-12-2025
Accepted: 13-01-2026

Jag Mohan
Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana, India

Neha Negi
Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana, India

Babita Bharti
Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana, India

Bharti Gautam
Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana, India

Amit Kumar
Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana, India

Ridhima Arya
Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana, India

Corresponding Author:
Jag Mohan
Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana, India

Climate change and agriculture: Adaptive strategies for resilient farming systems agriculture

Jag Mohan, Neha Negi, Babita Bharti, Bharti Gautam, Amit Kumar and Ridhima Arya

DOI: https://www.doi.org/10.33545/26174693.2026.v10.i1Sk.7109

Abstract
CRA refers to the application of mitigation, adaptation, and other agricultural methods that improve the system's ability to withstand harm and bounce back swiftly from a variety of climate-related disruptions. Events like drought, flooding, heat or cold waves, irregular rainfall patterns, protracted dry spells, explosions in insect or pest populations, and other perceived threats brought on by climate change are examples of such perturbations and disruptions. It is, in essence, the system's capacity to recover. A built-in feature of climate resilient agriculture is the ability to identify threats that require action and assess how well those actions are working. By implementing best practices, CRA will primarily entail the prudent and enhanced management of natural resources, including soil, water, land, and genetic resources.

Keywords: Climate, Climate resilient agriculture, drought and cold wave

Introduction

Human activities, such as industrialization and deforestation, have brought about notable, sustained changes in temperature and weather patterns, resulting in the phenomenon referred to as modern climate change or human-induced climate change (Karl and Trenberth, 2003; Wilson and VanBu ren, 2022) [19, 45]. These acts raise carbon dioxide levels, which exacerbates the greenhouse effect and jeopardizes the stability of the global climate (Rhodes *et al*., 2021; Toledo-Gallegos *et al*., 2022; Ward, 2022; Zong *et al*., 2022) [26, 41, 44, 47]. As a result, global temperatures have risen by 1° projections indicating further increase of 1.5°C since the 1950s, with C by 2030-2052, posing severe risks to global food security and agricultural productivity, mainly in low- and middle-income nations (Acevedo *et al*., 2020; Islam *et al*., 2022; IPCC 6th Assessment ReportWG1, 2021; United Nations, 2015; NOAA, 2024; Zong *et al*., 2022; Zizinga *et al*., 2022) [1, 17, 47, 46]. In India, where agriculture is the backbone of the rural economy, climate-related stresses (e.g., erratic precipitation, pest infestations, and extreme weather events) significantly impact agricultural stability (Dagar *et al*., 2012; Dar *et al*., 2020a; Singh *et al*., 2021) [9, 10, 23]. The nation's diversified environment, while supporting a wide range of crops, also heightens the threat to critical staples like wheat and rice. Projections of a 2.8ºC temperature increase by 2050 highlight the urgent need for robust climate-resilient agriculture (CRA) strategies across various agro-climatic zones in India (Srivastav *et al*., 2021; Birthal *et al*., 2021; Rao *et al*., 2019a; Singh *et al*., 2021; Shanabhoga *et al*., 2020) [38, 6, 25, 23, 29]. CRA can offer a viable option to increase resilience, production, and carbon sequestration by fusing old knowledge with contemporary methods (Birthal *et al*., 2021; Singha *et al*., 2024; Angom and Viswanathan, 2023; Goswami *et al*., 2023; Shiiba, 2022) [6, 35, 3, 12, 31]. Global case studies demonstrate the CRA's efficacy in improving food security and water management (Sekaran *et al*., 2021) [28].

The need for CRA in India

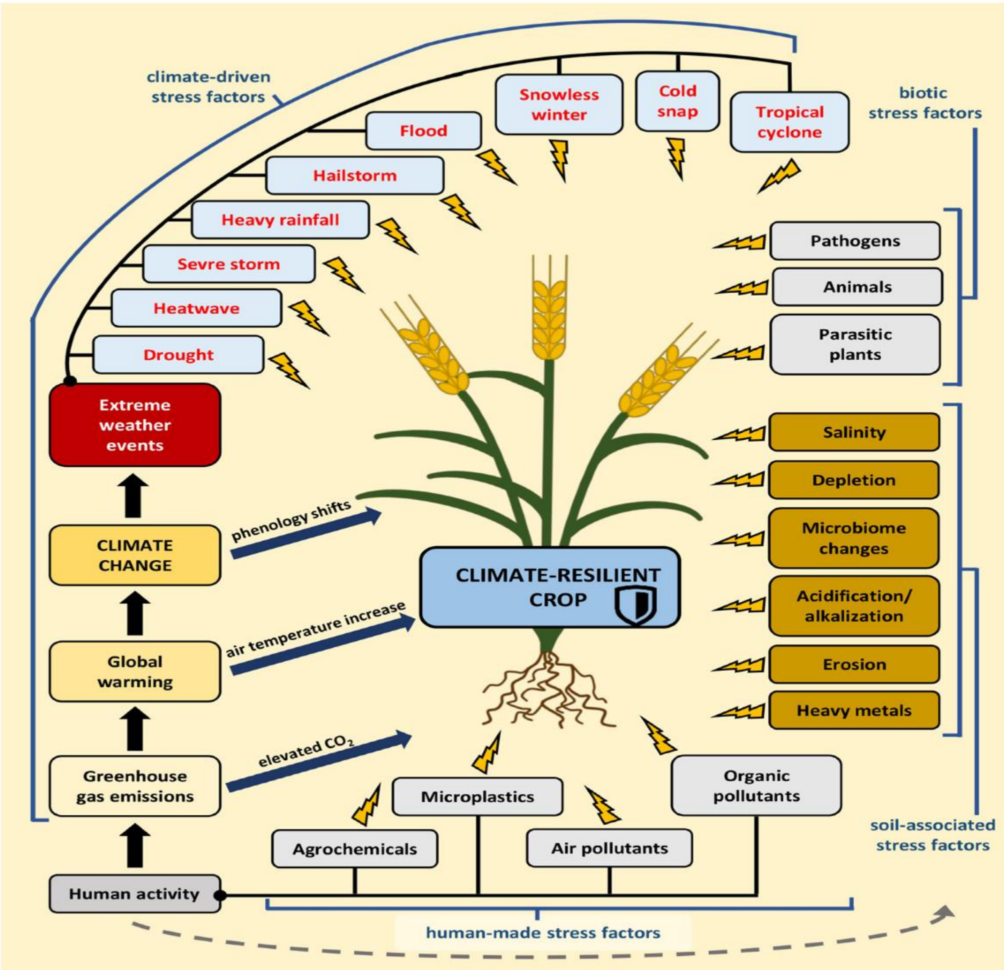
According to global population estimates, India was the second most populous nation after China, with a population of 1.38 billion in 2020 (The Economic Times, 2023). Despite occupying only 2.4% of the world's land area, the average landholding size in India is merely 1.08 ha per state. About half of all farmers in Indian states are small farmers, who possess one to two hectares. These small-scale farmers deal with a number of issues, such as limited access to inputs, poor market infrastructure, and inadequate transportation. In 2019-20, agriculture produced 291.95 million metric tons of food despite climate risks, supporting 58% of the population and 70% of rural families (82% of farmers are small and marginal) (Borkar, 2019; FAO, 2023a). Poverty, unequal regional growth, urbanization issues, and unsustainable farming practices are all made worse by the fast expanding population, which is expected to surpass 1.5 billion by 2030 and 1.64 billion by 2050 (Gulati *et al*., 2023; United Nations, 2019) [13].

The need for wholesome food from rural areas already under stress from climate change effects including rising temperatures, droughts, groundwater depletion, and extreme weather that affects river basins will increase by 2030 due to this growing population and growing urbanization (IPCC, 2018). In order to address these issues and promote economic growth, food production must double by the year 2050. Small and marginal farmers are essential to attaining the SDGs and guaranteeing the nation's food security (Pawlak and Kołodziejczak, 2020) [24]. Supporting these farmers can significantly advance SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land). However, agricultural productivity, nutrient cycles, and fertilizer effectiveness are at risk due to climate-induced extreme weather and a projected 1-2.5°C temperature increase by 2030 (Rao *et al*., 2019a) [25].

Impact of Climate Change on Indian Agriculture

Agriculture is impacted by climate change in both direct and indirect ways. The degree of climatic change, geographic location, and production system type will all affect the kind and extent of the impact. Simulation modeling and controlled experiments are used to evaluate the effects of climate change.

Effects on agricultural crops



A climate-resilient crop is resistant to multiple stress factors, which can be abiotic, including both human-made and climate-driven factors, as well as soil-associated or biotic stress factors. Human activity generates greenhouse gas emissions, including carbon dioxide, that accelerate global warming, leading to climate change. This, in turn, could impact the frequency of extreme weather events and shifts in plant phenology. Human activity also influences the soil and exacerbates soil-associated stresses.

Shortening crop duration, which is connected to the thermal environment, has the biggest impact on crops. Crop maturity will be accelerated by temperature increases. The reduction in crop duration for annual crops might range from two to three weeks, which has a negative effect on productivity. Temperature has a direct impact on the processes of fertilization, pollination, and reproduction in crops including rice, wheat, sunflower, and others. Changes in water availability brought on by insufficient or excessive rainfall and the impact of rising temperatures on the occurrence of pests and diseases are examples of indirect influences. According to modeling studies, important crops including maize, rice, and wheat would yield less as a result of climate change. In contrast, the effects on chickpeas, soybeans, and groundnuts may be neutral or even beneficial. The crop-wise impacts are described below:

Rice

In recent years, India's monsoon has grown more unpredictable and chaotic. The latter half of the past 50 years has seen a decrease in the number of rainy days and an increase in the frequency of strong rainfall events. The nation's wet-season (kharif) rice harvest is now more vulnerable to drought and flooding. In mostly rainfed areas, rice yield was negatively impacted by drought and excessive rainfall between 1966 and 2002, according to statistical studies of state-level data.

Extreme rainfall occurrences have been proven to have a significantly smaller influence than the drought (Auffhammer *et al*., 2012) [5]. Climate change is expected to decrease irrigated rice yields by around 4% in 2020 (2010-2039), 7% in 2050 (2040-2069), and 10% in 2080 (2070-2099) climate scenarios, according to the average of all emission scenarios. In contrast, rainfed rice yields in India are predicted to decline by about 6% in the 2020 scenario, but only slightly (less than 2.5%) in the 2050 and 2080 scenarios (Soora *et al*., 2013) [36].

Wheat

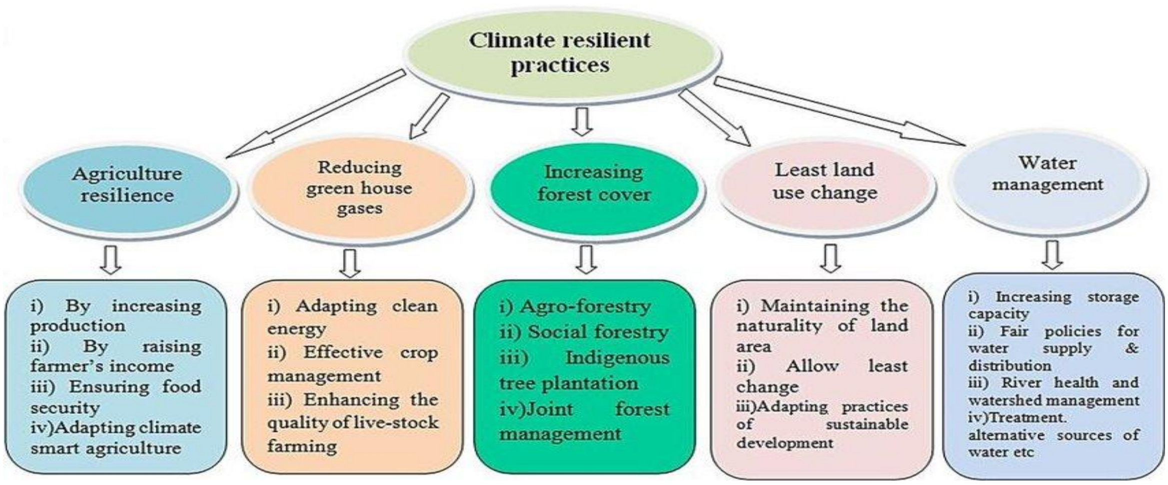
According to early wheat modeling studies, India may lose four to five million tons of wheat for every degree Celsius that the mean temperatures rise (Aggarwal, 2008) [12]. By 2050, 15% of the world's wheat production is expected to come from the Indo-Gangetic Plains (IGPs) due to the current forecast changes in the environment. Up to 51% of this land has to be categorized as a short-season, heat-stressed, irrigated crop (Ortiz *et al*., 2008) [23]. If suitable cultivars and crop management techniques are not developed and embraced by farmers, this change would also lead to a considerable decrease in wheat yields. In addition to the effects of rising temperatures, excessive heat has been observed to accelerate senescence in Indian wheat. According to these findings, wheat faces an even bigger threat from global warming than was previously shown by modeling studies, and the success of adaptations will rely on how successfully they lessen crop susceptibility to extremely hot days (Lobell *et al*., 2012) [20].

According to model predictions, crop yields will decrease as a result of a shorter growth period brought on by rising temperatures. The yield decreased more when the maximum temperature rose than when the minimum temperature rise (Jalota *et al*., 2013) [18]. It has also been observed that different environmental conditions cause different responses from wheat cultivars. Using DSSAT v4, simulation studies were conducted to assess the growth and yield characteristics of wheat genotypes under timely and late-sown conditions in various parts of India. The results demonstrated that there was significant variance across genotypes in anthesis, maturity duration, grain number, and yield (Attri *et al*., 2011) [4].

Maize

India's Mid Indo-Gangetic Plains (MIGP) and Southern Plateau (SP) are expected to see a decline in winter (Rabi) maize grain yield as temperatures rise. The predicted changes in temperature and precipitation throughout time and space are likely to have varying effects in various regions (Byjesh *et al*., 2010) [8]. Specifically, while upper IGP yields will remain mostly unaltered, monsoon season output in SP may decrease by up to 35%, and winter yield in MIGP may decrease by up to 55%. To reduce the vulnerability of maize production in India, it may be beneficial to develop new cultivars whose growth patterns under altered climate scenarios are comparable to those of existing types under current conditions (Byjesh *et al*., 2010) [8]. Making use of simulation models and field experiments According to Singh *et al*., temperature variations related to the dates of planting had a significant impact on maize growth and yield.

The detrimental effects of cold temperatures resulted in a decrease in yield for crops that were planted later. In 2020 and 2050 scenarios, irrigated wet-maize is expected to diminish yields by as much as 18%. In scenarios for 2080, this negative impact of climate change is estimated to be roughly 23%. The net productivity of irrigated maize can be increased by roughly 21% in 2020, 10% in 2050, and 4% in 2080 scenarios by using adaptation tactics including enhanced and tolerant cultivars managed under improved inputs with more nitrogen fertilizer (Soora *et al*., 2012) [37].



Other crops

The A2, B2, and A1B scenarios, which depict a future world with dynamic levels of economic growth and global population, predicted mean temperatures in cotton-growing regions of India to rise by 3.95, 3.20, and 1.85°C, respectively, according to general circulation models (GCMs). Seed cotton yield decreased by 477 kg ha−1 for the A2 scenario and by 268 kg ha−1 for the B2 scenario, according to simulation results using the INFOCROP-cotton model (Hebbar *et al*., 2013) [14]. To boost and maintain groundnut productivity in the face of climate change, several combinations of adaptation techniques will be required (Singh *et al*., 2013b) [32]. It is anticipated that groundnut yields will drop by 5% over the long term and by 7% over the medium term, while the area planted to groundnuts will decrease by 5% and 4%, respectively (Soora *et al*., 2012) [37].

Effect on Horticulture

According to the A1B 2030 scenario, climate change may result in a 3%-7% increase in potato production in Punjab, Haryana, and western and central Uttar Pradesh, but a 4-16% decrease in production in the rest of India, especially in West Bengal and the Southern Plateau region. This is mainly because the mean minimum temperature during tuber development stages rises, which impacts potato yield (Soora *et al*., 2012; Singh *et al*., 2013a) [37, 34]. Vegetables and potatoes mature early, and crops exposed to unusually high temperatures (heat waves) will experience significant crop losses. Climate variability has also had an impact on grapes and their value-added products. With the possibility of a shift in the frequency and pattern of insect pest attacks, such as mealy bugs, thrips, and mites, it is anticipated that grape yields may decline (Sharma *et al*., 2013) [31].

A significant horticultural commodity focused on exports, cashew nuts are also likely to be impacted by climate change, which will have an impact on export earnings. Climate fluctuation has a greater impact on cashew nut and kernel quality, yield, insect-pest incidence, flowering, and fruiting. The main elements that negatively impact cashew nut productivity and quality are excessive dew and unseasonable precipitation throughout the flowering and fruiting seasons (Rupa *et al*., 2013) [27]. In India, oil palm is cultivated using irrigation. Because of its inadequate adaptation strategies and over-reliance on groundwater, it is probably more susceptible to climate change (Suresh *et al*., 2013) [40].

Effect on Livestock

Livestock productivity and economic viability may be impacted by climate change. Climate change will have a more negative impact on dairy cattle than on other livestock. In India, animal heat stress is a major worry. Reduced ovarian follicle growth, size, and development, fertility rate, oestrus period duration and intensity, increased risk of early embryonic mortality, and lower fetal growth and calf size are the main impacts. All animals' methods and rates of heat uptake or loss are directly impacted by environmental conditions brought on by climate change (Mader *et al*., 1999) [21].

Heat stress can also affect other intensive animal production systems, like pig farms and poultry farms. Reduced feed intake, laying performance (chickens), reproductive levels, decreased activity, and, in the worst situations, higher mortality are some of the reactions. Milk output is predicted to decline by 1.6 million tonnes by 2020 and by 15 million tonnes by 2050 due to global warming. In the first lactation, the yield reduction can range from 10-30%, whereas in the second and third lactations, it can range from 5-20% (Srivastava, 2010) [39]. Temperature increases in 2040-2069 and 2070-2099 are projected to have a greater detrimental effect on milk output from cattle and buffalo in Northern India.

CRA initiatives and projects in India

National Innovations in CRA (NICRA) (2010-2011)

NICRA was a comprehensive, multidisciplinary network project that was started in 2011 by the Indian Council of Agricultural Research (ICAR) with the goal of making Indian agriculture more resilient to climate change and variability (URL: http://www.nicra-icar.in/). The project's primary goals were to increase agricultural adaptation, provide tailored technology packages and solutions to address climate-related issues in farmers' fields, and develop the expertise of stakeholders and scientists.

Enhancing adaptive capacity and increasing resilience of small and marginal farmers in Purulia and Bankura district of West Bengal (2015-2019)

The Development Research Communication and Services Centre (DRCSC) was in charge of this initiative, which sought to establish climate-resilient and adaptable livelihood strategies for small and marginal farmers in the Lateritic Zone of West Bengal (URL: http://www.drcsc.org/ and https://www.nabard. org/). Through excellent natural resource management, technology integration, and diversification, this project primarily focused on agriculture and adjacent industries. By putting policies in place to lessen the negative effects of climate change on their food and livelihood security, the program seeks to increase the adaptive ability of vulnerable agricultural households in the semi-arid regions of Purulia and Bankura districts. A large number of households are intended to profit from it, including many members of fragile farming communities and those who depend on natural resources.

Scaling-up CRA towards climate-smart villages (CSVs) in Haryana (2016-2019)

Through the promotion of CRA practices in a few chosen areas, this project aimed to enable rural communities in Haryana to adapt to climate change (URL: https://www.nabard.org/). Many families in many villages in various districts, including as Yamunanagar, Ambala, Kurukshetra, Karnal, Jind, Kaithal, Panipat, Sonipat, Sirsa, and Fatehabad, benefited from this project. The Department of Agriculture, Government of Haryana, was in charge of the project, which also had a sizable budget.

Resilient agricultural households through adaptation to climate change in Mahbubnagar district, Telangana (2016-2020)

The goal of this project was to use appropriate and science-based CRA techniques to improve the standard of living for farming people in certain villages (URL: https://www.nabard.org/). Through the establishment of climate-resilient cropping patterns, effective irrigation techniques, soil and water conservation, and forecasting model development, the project sought to advance sustainable farming practices in the region. It also aimed to disseminate information and experiences to the larger community. A considerable number of farming households in the Mahbubnagar area were expected to gain, with women making up 30-50% of the beneficiaries. Additionally, it was anticipated that this project would be most beneficial to small and marginal farmers.

Climate resilient sustainable agriculture in rain-fed farming areas of Jammu and Kashmir (2016-2020)
This initiative was carried out by the government of Jammu and Kashmir's agriculture production department in order to increase the farmers' resistance to climate change in the area.
(URL: https://www.naba rd.org/). Reducing farmers' susceptibility to water stress, encouraging suitable farming practices and rainwater collection, and strengthening farmers' ability to adapt particularly for small and marginal farms were the primary objectives of the initiative.

Scaling climate-smart agriculture through main streaming climatesmart villages in Bihar (2017-2020)
Zero tillage, direct-seeded rice, cropping system optimization/diversification, residue management, decision support (nutrition expert), sensor-based site-specific nutrient management, precision water management (laser leveling), stress-resistant cultivars, capacity building, and information sharing with the general public were among the conservation agriculture practices that the project sought to promote (URL: http s://www.nabard.org/). It was carried out in four corridors Bhagalpur-Munger in Bihar, Katihar-Purnea, Samastipur-Darbhanga, and Bihar Sharif-Patna across several villages. With a Rs. 23.06 crore NAFCC funding, the project was carried out by the Bihar government's department of agriculture and benefited communities in the Banswara district.

Project on CRA- Maharashtra (POCRA) (2018-2024)
The World Bank and the Maharashtra government collaborated on the POCRA project. Its main objective is to create a climate-resilient plan for the state's farming industry (URL: https://proj ects.worldbank.org/). The project's goal was to address the possible impacts of climate change and its unpredictability while enhancing the profitability and climatic resilience of smallholder farming systems in different Maharashtra districts. The second phase of the project has been approved by the government and is scheduled to start in June 2024. It would include five additional districts: Nagpur, Bhandara, Gondia, Chandrapur, and Gadchiroli. to learn more about the CRA projects that are currently being offered in India.

Conclusion
This study examined CRA as a means of guaranteeing food security in India, pointing out the opportunities and difficulties related to sustainability in the nation. Extensive research on CRA techniques across different climate-resilient locations is necessary to effectively address the effects of climate change on agricultural economics.
Farmers' risk assessment, technological expertise and availability, family requirements, and financial situation all play a role in their decision to use CRA techniques. Therefore, programs should improve farmers' ability to make decisions and methodically create, verify, and share adaptive knowledge. In a changing climate, assistance is required for technology, institutions, funding, and the development of a knowledge base and transfer framework specific to various AEZs and local conditions. For climate action to be sustainable and effective, policymakers must comprehend and take farmers' perspectives into account. Promoting food security and enhancing livelihoods requires strong monitoring, stakeholder engagement, and resource accessibility.

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