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Effects of climate change on food security and nutrition in India: A systematic review

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A R T I C L E I N F O

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A B S T R A C T

Climate change poses a complex challenge to food and nutritional security, impacting human health, well-being, and sustainable development. India, facing heightened vulnerability in agriculture and a growing population surpassing 1.3 billion, requires a detailed examination of these effects. This examination will serve as a crucial resource for shaping policies, directing research efforts, and fostering public discourse. This systematic review thoroughly analyzes the impact of climate change on food and nutritional security in India. Examining 231 articles, the study delves into various dimensions, including availability, accessibility, utilization, and stability. The review utilized Web of Science, PubMed, and CABI review, employing 100 different keywords. Temperature variations, erratic rainfall, and extreme weather events disrupt crops, livestock, poultry, and aquaculture production (food availability), leading to food shortages, income loss, and elevated food prices (accessibility), especially affecting low-income groups. Indirectly, climate change affects livelihoods and incomes, exacerbating inequalities and leading to the displacement of marginalized communities (stability), thereby escalating food insecurity and malnutrition (utilization). However, few studies cover diverse aspects such as the influence of climate change on traditional crops, nutritional value, agricultural biodiversity, food distribution systems, indigenous food systems, and nutrition outcomes, particularly for vulnerable groups like women and children. Hence, there is a pressing need for a more holistic and integrated approach to tackle the impacts of climate change on food and nutrition security in India.

1. Introduction

Climate change(Kingra et al., 2019; United Nations, 2025)) is probably the most complex and intractable environmental challenge faced by the world today and is increasingly being recognized as a potent threat to agriculture in general and specific to food security (Pattanayak and Kumar, 2014; Mahapatra et al., 2021). Without a doubt, climate change is occurring and already has significant impacts through increased climatic variability, global temperatures, and sea level (Masters et al., 2010; Sharma et al., 2018). Climate change will continue to significantly impact agriculture, reflecting the close link between climate (temperature and precipitation in particular) and agriculture productivity. These effects are likely to have the greatest impact in the low-income countries of the tropical zones where agricultural productivity would decrease. Climate variability and change influence ecosystems, food security, health, and other domains fundamental to human existence and well-being (Ghosh-Jerath et al., 2021). An increased frequency of extreme events, heat stress, droughts, and floods negatively impact crop yields (Masters et al., 2010). These negative impacts of climate change on agricultural and food production have got the attention of the global research community to undertake rigorous research in this area (Joshi et al., 2016).

The situation in India is even more challenging as compared to the global scenario with the high vulnerability of agriculture to changing climate and continuously increasing demand for food for a large population of over 1.3 billion which is growing. An increase of 1–2 °C in temperature is going to have a significant negative impact on the yield of major food crops in low-altitude countries like India (Bhat and Pandit, 2020), which in turn will impact the nutritional status of the population (Gregory et al., 2005; Mahapatra et al., 2021).

In India, ensuring food security and nutrition is one of the highest priorities for policymakers. India's economy is heavily dependent on

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agriculture. Climate change significantly threatens the country's food security and nutrition. In recent years, extreme weather events such as floods, droughts, and cyclones have become more frequent and severe, disrupting food production and distribution systems as a result affecting the livelihoods of millions of people (Mahapatra et al., 2021; Gregory et al., 2005; Viswanathan and Kumar, 2015; Priyadarshi et al., 2019). Therefore, understanding the impacts of climate change and variability on various aspects of food security and nutrition is critically important for appropriate policymaking.

Although there is a growing body of literature on the effect of climate change on food security and nutrition in India, however, it is not known whether the evidence generated so far is sufficient to understand the effects of climate change on various key dimensions of food security and nutrition, i.e., food availability, accessibility, utilization, and stability, especially in Indian context. Therefore, it is essential to conduct a systematic review of the available literature to know the effects of climate change on food security and nutrition in India and to identify evidence gaps. This review is unique in its systematic assessment of the impacts of climate change on food security and nutrition, specifically in the Indian context. While several global and regional reviews address food security challenges, our study uniquely focuses on the multidimensional effects of climate change on food availability, accessibility, utilization, and stability in India, using a structured methodology based on a comprehensive synthesis of 231 research articles. Probably this systematic review is the first of its kind in the Indian context. This systematic approach not only identifies existing evidence but also highlights critical knowledge gaps that require further investigation. Additionally, given India's diverse agro-climatic zones and its significant place in global food systems, the findings from this review offer valuable insights for other developing countries facing similar climate-induced food security challenges. By providing a detailed, evidence-based framework, our review can serve as a reference for policymakers and researchers working on climate adaptation strategies both within India and in broader international contexts.

This review enables a better understanding of the effect of climate change on food security and nutrition in India and will inform the development of appropriate policies and programs to address this critical challenge. The review also identifies research evidence gaps in the current literature and highlights the need for expanded and future research. Finally, this systematic review will provide evidence support to policymakers and other stakeholders to make informed decisions to improve food security and nutrition for better adaptation to climate change.

After this brief introduction, the following section presents the methodology used for conducting this review. Next, we discuss the study characteristics across different aspects. In the next section, we explore the literature on the effect of climate change on food security and nutrition, and in the next section, we further investigate the potential areas for future research. Finally, the last section concludes with the findings from the systematic review and provides the policies to mitigate climate change based on this systematic review.

2. Methods

2.1. Protocol

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines used for conducting this study (Moher et al., 2009).

2.2. Search strategy

We systematically and extensively searched published research using the three most useful and popular electronic bibliographic databases: Web of Science, CABI, and PubMed.

In the first stage, we identified and pinned down our search to five themes related to food security: Climate change and Food Security, Food Availability, Food Accessibility, Food Utilization, and Food Stability. We further divided these themes into various subthemes. Finally, we used a unique set of keywords in each distinct subtheme. In total, we used 100 unique keywords for this systematic survey.

For the intra-sub-theme search, we used, OR between the words, and for the inter-sub-theme search, we used AND for all of the queries. In the second stage, we use two filters: publication time (January 1990–October 2022) and language (English). At the beginning of April 2022, a test run was done for our search method in the CABI database, and then it was replicated in all other databases between 18th October and 21st October 2022.

2.3. Eligibility criteria and study selection

After removing duplicates, we found 9271 articles from these three databases. Our main objective was to identify the effect of climate change on food security and nutrition in India. We used five criteria in different screening phases to determine the eligibility for inclusion (exclusion) of the relevant (irrelevant) articles from our search database. All the screening phases and inclusion/ exclusion criteria are presented in Table 1 in the Appendix.

3. Study characteristics

From the search of three bibliographic databases and different web searches, we retrieved 9271 articles. After using the search criteria (described in the previous section), finally, we pin down 231 research studies. The detailed PRISMA flow diagram (Fig. 1) shows step-by-step maps of the number of records identified, included, and excluded and the reasons for exclusions for undertaking the present review.

3.1. Dimension-wise distribution

The allocation of research studies on India, as illustrated in Fig. 2, demonstrates the multifaceted nature of comprehending and tackling the impacts of climate change on food security and nutrition. This encompasses various dimensions, including food availability ($n = 136$), food accessibility ($n = 31$), food utilization ($n = 40$), and food stability ($n = 30$). These dimensions collectively contribute to understanding complex relationship between climate change and food security in India.

The findings presented in Fig. 2 reveal that the majority of research efforts have been concentrated on the dimension of food availability, particularly concerning the impact of climate change on cereals production ($n = 45$), legume production ($n = 9$), and oilseed production ($n = 12$). This emphasis indicates a significant interest among researchers in understanding crop productivity and enhancing food availability to comprehend climate change's effects on food security and nutrition. In comparison, research studies within the livestock sub-dimension ($n = 31$), focusing on big ruminants ($n = 17$), small ruminants ($n = 8$), and poultry birds ($n = 6$), are relatively fewer compared to crop production. The number of research studies dedicated to understanding the impact of climate change on aquaculture production ($n = 21$) is also relatively low, followed by fruit and vegetable production ($n = 18$). This detailed comparison demonstrates that crop production, particularly cereals, receives the greatest research attention, reflecting its crucial role in global food security. However, there is also significant recognition of the importance of livestock production, aquaculture, and fruit and vegetable production which are sources of diverse and nutritious food.

Although the number of research studies on the dimensions of food accessibility ($n = 31$), food utilization ($n = 40$), and food stability ($n = 30$) is not as extensive as that in food availability, it still reflects a

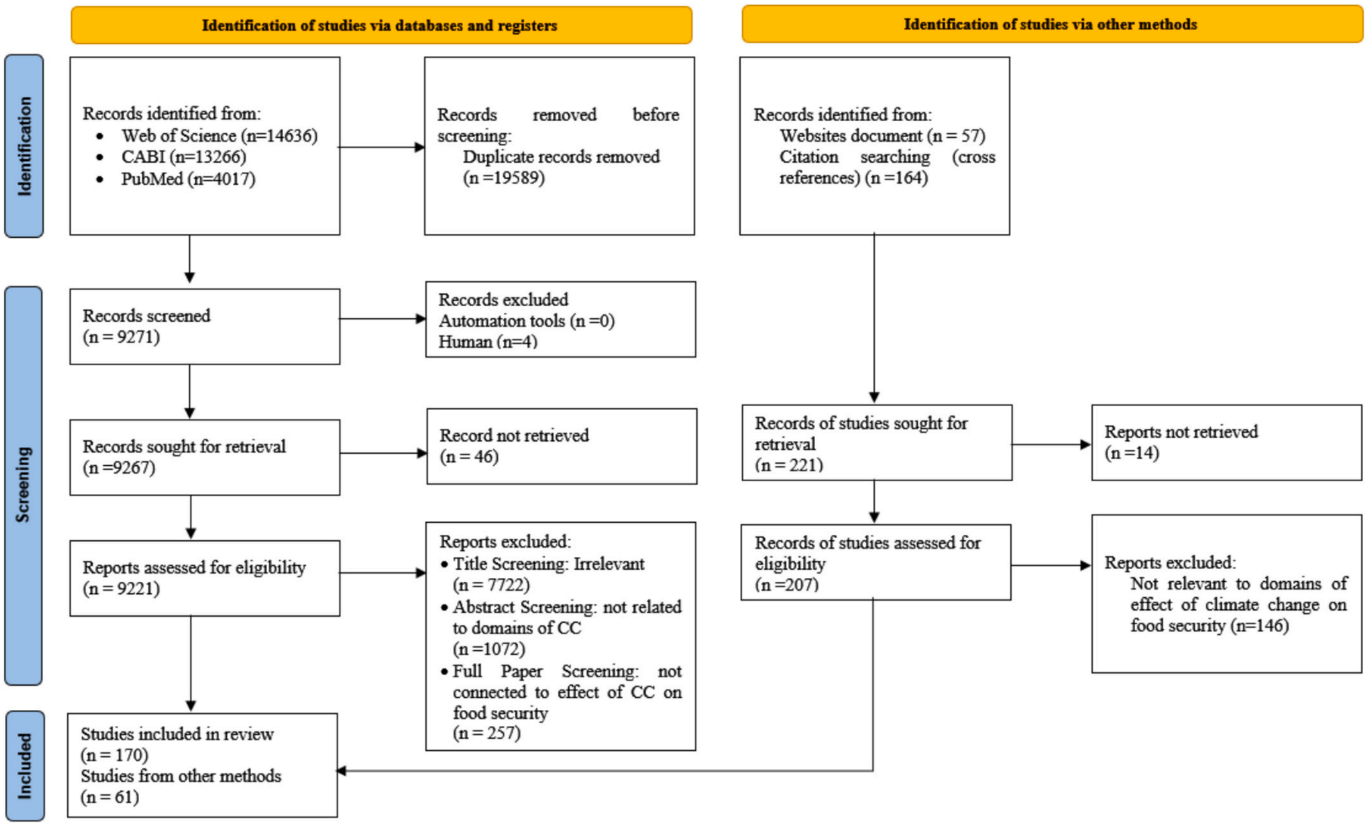

Fig. 1. PRISMA flow diagram of the systematic review on effect of climate change on food security and nutrition in Indian context.

significant interest in these aspects of food security and nutrition. Within the sub-dimensions of food accessibility, there is a relatively lower number of studies focusing on the effects of prices and the risk of hunger ($n = 16$), land use ($n = 7$), and storage ($n = 8$). Similarly, in the sub-dimensions of food utilization, research studies on food safety ($n = 17$) and food quality (n = 17) are comparatively fewer. The sub-dimensions of food stability, such as the effects of extreme events ($n = 25$) and food aid distribution ($n = 5$), have received the least amount of research attention, suggesting potential areas for further investigation and intervention to address specific challenges within these aspects of food security. Despite the imbalance in the number of studies, these findings indicate the recognition of the importance of comprehending and addressing all dimensions of food security to ensure overall nutrition and well-being.

3.2. Year-wise distribution

Over the past decade, a growing focus has been on studying climate change and its effects on food security and nutrition concerning India. In the period from 1990 to 2010, there was limited literature available (27 publications) that addressed the topic of this review article for India. However, starting in 2010, there has been a significant increase in interest and importance, with 203 relevant publications by researchers aiming to understand the impact of climate change on food security and nutrition in India. Notably, the year 2021 had the highest number of publications ($n = 31$), followed by 2019 ($n = 29$), 2020 ($n = 21$), and 2022 ($n = 20$). Please refer to Fig. 3 for a detailed listing of publications by year, considering research studies until October 2022 for the present review.

3.3. State-wise distribution

Fig. 4 depicts the intensity of the research conducted and the focus on understanding the relationship between climate change and food security in India's different states and union territories.

The number of studies undertaken varied significantly across regions. Odisha ($n = 32$) has the highest number of research studies indicating a strong focus on understanding the effect of climate change on food security in that state. Karnataka($n = 30$) and Andhra Pradesh($n = 28$) also have number of studies. On the other hand, Union Territories (Chandigarh, Dadra & Nagar Haveli, Daman & Diu, Lakshadweep, and Puducherry) have only 2 studies each, suggesting a comparatively lower research emphasis in those regions.

Some highly populated states have a substantial number of studies, such as Uttar Pradesh ($n = 25$), Maharashtra(n = 25), Bihar ($n = 24$), West Bengal (n = 25), and Andhra Pradesh ($n = 28$) which are among the most populous states in India. This suggests that researchers and policymakers recognize the importance of studying the impact of climate change on food security in highly populated regions where the consequences can be significant and widespread.

The variation in the number of studies conducted across States and Union Territories reflects different levels of attention and priority given

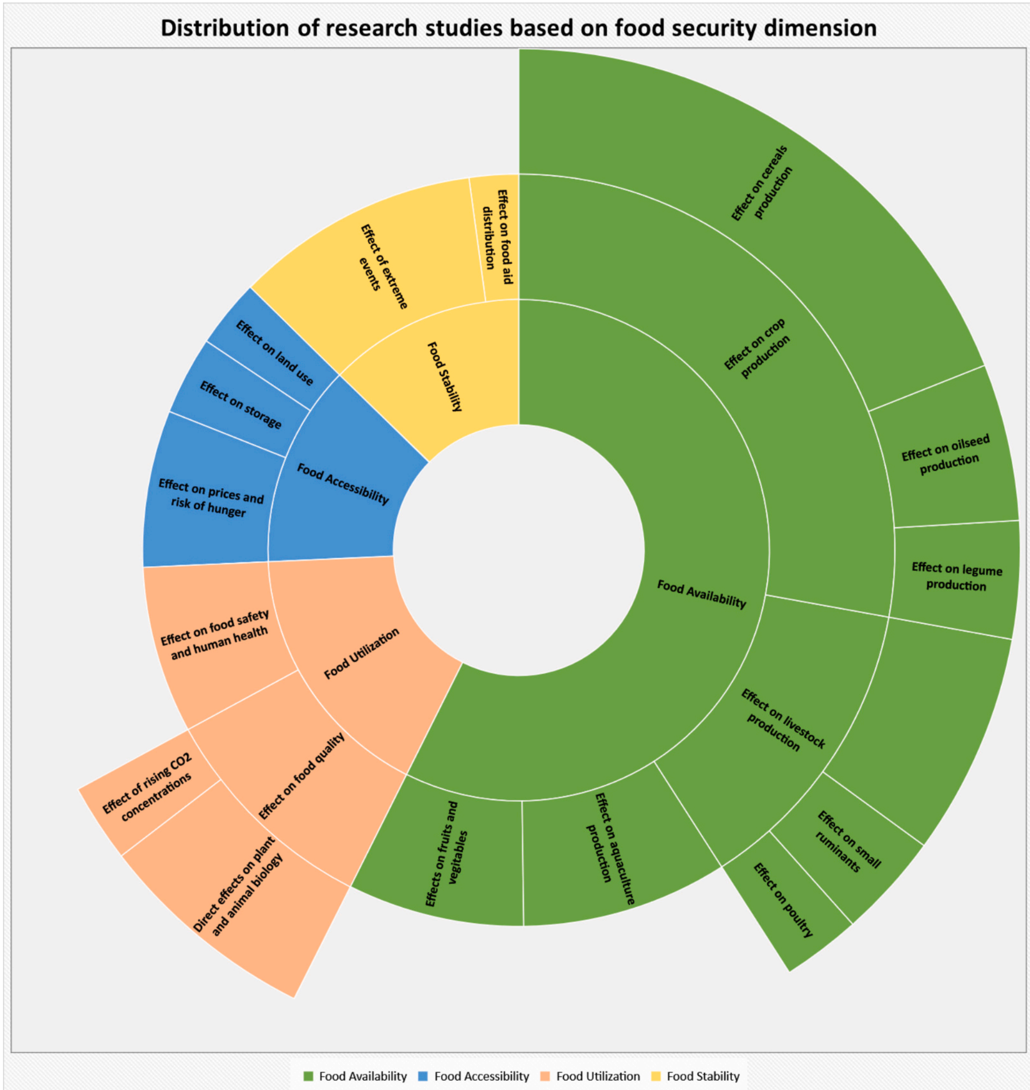

Fig. 2. Distribution of research studies based on food security dimensions.

to the issue of climate change and food security and nutrition. States with higher numbers of studies may be more equipped to develop localized strategies, policies, and interventions to mitigate the impacts of climate change on food security and nutrition.

It is important to note that the number of studies alone does not indicate a comprehensive understanding of the effectiveness or depth of research conducted in each region. Individual studies' quality, scope, and impact should also be considered while evaluating India's overall research landscape on climate change and food security.

3.4. Climate attributes wise distribution

In the review, we have identified (from the literature) four important environmental variables related to climate change and their combinations including Temperature, Rainfall, Extreme Events, and Others to understand the effect of climate change on food security and nutrition of India. Here we are composed of environmental attributes such as temperature ($n = 140$), rainfall ($n = 82$), extreme events ($n = 64$), and others (n = 14). We also looked at different combinations, including temperature and rainfall ($n = 69$), temperature and extreme events ($n = 23$), temperature and others ($n = 7$), rainfall and extreme events ($n = 19$), rainfall and others (n = 1), and a mix of temperature, rainfall, and extreme events ($n = 15$).

4. Effect of climate change on food security and nutrition

4.1. Framework

The effect of climate change on the four fundamental components (Abisha et al., 2022) of food security[1] (Table 1), namely food availability, food access, food utilization, and food stability, is important as noted by FAO (FAO, 2002; 2006). To comprehensively understand the effect of the phenomena, we have examined the climate change effects on various subcomponents within each of these fundamental

[1] Recent literature added 2 more dimensions of food security along with the availability, accessibility, utilization, and stability. These two additional dimensions proposed by the High-Level Panel of Experts on Food Security and Nutrition namely agency and sustainability. Agency, refers to "the capacity of individuals and groups to exercise a degree of control over their own circumstances and to provide meaningful input into governance processes, is widely seen today as an important aspect of addressing widening inequities within food systems, including imbalances of power among actors within those systems" (Clapp et al., 2022). Sustainability refers to "food system practices that contribute to long-term regeneration of natural, social, and economic systems, ensuring the food needs of the present generations are met without compromising food needs of future generations" (HLPE, 2020)

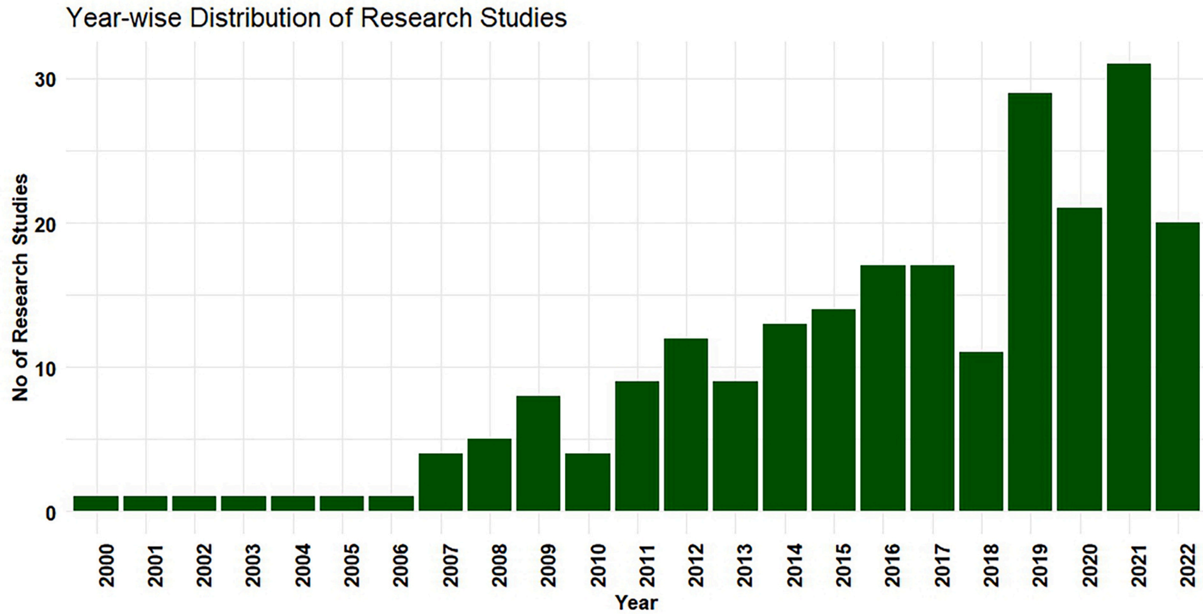

Fig. 3. Year wise distribution of research studies.

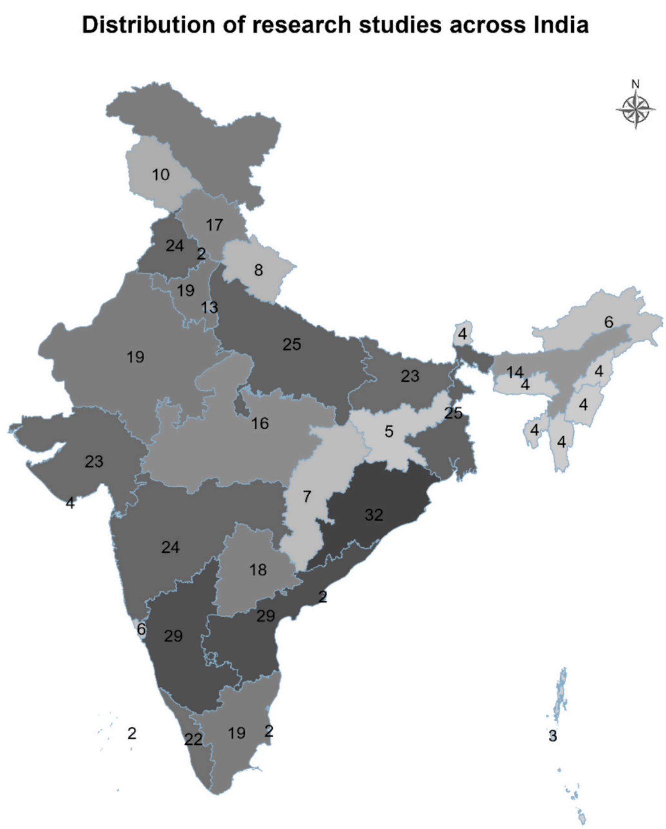

Fig. 4. Distribution of research studies across India.

components. In the present systematic review, we have implemented a methodological approach from IPCC (Mbow et al., 2019) to understand the effect of climate change on food security and nutrition in India.

A. Climate Change Effects on Food Availability

In this section, the effects of climate change on food availability have been analyzed across four components: the effect on crop production, the effect on fruit and vegetable production, the effect on livestock production, and the effect on aquaculture production.

Table 1
Component of Effects of climate change on food security and nutrition.

Effects of climate change on food security and nutrition			
On Food Availability	On Food Accessibility	On Food Utilization	On Food Stability
● effect on crop production ● effect on livestock production ● effect on aquaculture production	● effects on Prices and Risk of Hunger ● effects on land use	● effects on food safety and human health ● effects on food quality	● effects of extreme events ● Food aid

A.1 Effect on crop production

The effects of climate change and variability on crop production are discussed in three parts: the effect on cereals, legumes, and oilseeds production.

A.1.1 Effect on cereals production

The effects of climate change and variability on cereals production in India are significant and multifaceted, with rising temperatures, changing precipitation patterns, and more frequent extreme weather events leading to significant economic losses for farmers and likely to threaten the country's food security (Panikkar et al., 2022; Martin et al., 2008; Kumar and Sharma, 2022; Singh et al., 2022; Rao et al., 2022; Paudel et al., 2021). Climate change has led to increase in the frequency of extreme weather events like heat waves, floods, droughts, hail, cyclones, etc., and poses significant threats to cereals production in India, which causes (Malhi et al., 2021; Birthal et al., 2014) huge economic losses to farmers.

Temperature change is one of the most important climatic change drivers affecting cereals production in India (Datta and Behera, 2022). Studies have shown that the effects of change in temperature on rice, wheat, and maize yield in India are complex and vary from region to region (Jha et al., 2021; Jamil Ahmad et al., 2011; Mandal and Singha, 2020; Singh et al., 2019). Research has shown that rising temperatures reduce yields ranging between 10 and 40 % for rice, 2–10 % for wheat, 2–12 % percent for maize, and 10–12 % for sorghum crop (Niranjana et al., 2020; Nidumolu et al., 2015; Yadav et al., 2015; Praveen and Sharma, 2020; Savary and Willocquet, 2020; Senguttuvel et al., 2022; Kingra et al., 2019; Aryal et al., 2019; Sinha and Swaminathan, 1991; Mukherjee et al., 2019a, 2019b; Madhukar et al., 2021; Sonkar et al., 2019; Kaul and Ram, 2008; Guntukula and Goyari, 2020) delay crop maturity and increase pest and disease, causing economic losses for farmers (Praveen and Sharma, 2019; Chakrabarty, 2016). Moreover, climate change shifts the sowing time and length of growing seasons geographically, altering the planting and harvesting period of crops and varieties currently used in some areas of Arunachal Pradesh (Shukla et al., 2014). Some studies have also suggested that rising temperatures increase water scarcity and may further affect cereals production in India (Sengar & Sengar, 2014; Kaushika et al., 2019; Kashyap and Agarwal, 2021).

Changes in precipitation patterns are another significant climate-related variable that affects cereal production in India. Research has shown that rice (10–30 %), wheat, and maize (2–12 %) yields in India are likely to decline due to changes in precipitation patterns (Chand and Dhaliwal, 2020; Panda et al., 2019; Senapati, 2022; Guntukula, 2020; Ghosh-Jerath et al., 2021; Tripathi et al., 2016; Saravanakumar et al., 2022). Sorghum yields in India are expected to decline due to changes in rainfall patterns (Saravanakumar, 2015; Tirlapur and Desai, 2017). However, increased precipitation in West Bengal, Odisha, and Assam in the east, coastal Andhra Pradesh, and coastal Tamil Nadu (located in the southern Peninsula), Madhya Pradesh (in central India), and parts of Uttar Pradesh and Punjab may increase the kharif rice yields in those areas (Chandio et al., 2021; Revadekar and Preethi, 2012). Studies have also shown a significant negative effect of precipitation change on maize yields in Telangana (Guntukula and Goyari, 2020).

The research shows that the adverse impact of drought on Indian agriculture much more than that of the flood. Rabi (post-rainy) food grain production depicts better adaptability to drought than Kharif (rainy season) food grain production primarily due to fact that rabi crops are grown under irrigation and the kharif crops mostly as rainfed (Singh et al., 2011; Arora et al., 2019). A negative effect of heat waves has been observed on cereals production in Punjab, Uttar Pradesh, and Bihar (Lobell et al., 2012).

A.1.2 Effect on legume production

Climate change also adversely affects legume crops' growth and productivity in India. Temperature, as a critical environmental factor, plays a significant role in the growth and yield of legume crops. Studies show that the rising temperature due to climate change has harmed pulse production in India (Pooja et al., 2019; Singh et al., 2021a, 2021b, 2021c). The yield of chickpeas, lentils, and green gram has been reported to be reduced due to the increase in temperature in Punjab (Singh et al., 2021a, 2021b, 2021c). Studies indicate that increased temperature during the reproductive phase has significantly reduced chickpea yield in Punjab, Telangana, and Uttar Pradesh (Farooq et al., 2017; Kaushal et al., 2013).

Changes in rainfall patterns also have a detrimental effect on legume productivity in India. Increased frequency of heavy rainfall events negatively affects pulse production in India (Mishra et al., 2017; Mohapatra et al., 2022). However, evidence from Uttar Pradesh shows that yield was reduced for selected legumes like soybean due to decreased annual rainfall (Dubey et al., 2011).

Extreme weather events, such as droughts and heat waves, result in reduced productivity of legume crops a 40–45 % decline in chickpea production in certain cases. Studies show that droughts have harmed legume productivity, particularly in rainfed regions (Rani et al., 2020; Kumari et al., 2021).

A.1.3 Effects on oilseed production

Temperature is a critical factor that affects oilseed production. Increasing temperature due to climate change affects oilseed crops in India and reduces crop yield (Yadav et al., 2016; Pasala et al., 2018). High temperature negatively affects the productivity of rapeseed and mustard crops, as observed in Bihar (Tesfaye et al., 2017). Soybean in Madhya Pradesh and Rajasthan was found to be more vulnerable to an increase in maximum temperature than the minimum temperature (Narolia et al., 2018; Agrawal et al., 2009).

Moreover, extreme weather events like droughts reduce the productivity of oilseed crops based on the evidence from Gujarat on groundnut (Patel et al., 2012) and mustard production in Rajasthan (Chauhan et al., 2007).

Changes in precipitation patterns due to climate change significantly affect oilseed production (sunflower production declines by 5 %) in India (Birthal et al., 2014; Sreekanth et al., 2013). It is found that adequate precipitation, but not high intensity is necessary for sesame production (Choudhary et al., 2022), and rainfall pattern change positively affects groundnut yield based on studies from Uttar Pradesh (Ahmed et al., 2019) as well as country level study in India (Birthal et al., 2014). However, floods have been reported to significantly reduce sesame production in the country due to waterlogging and soil erosion (Yadav et al., 2022).

A.2 Effect on Fruits and Vegetable Production

Fruit and vegetable production is highly vulnerable to climate change at their reproductive stages and also due to increased disease incidence because of climate variability. Rising temperatures and reduced precipitation are bound to affect the horticultural crops of the region (Sarkar et al., 2021a, 2021b; Paudel et al., 2021). The effects can be at any crop growth and development stage, thus influencing the quality and yield (Bhardwaj and Sharma, 2012).

Climate change is causing changes in temperature patterns that significantly affect fruit and vegetable production in India. Studies have shown that high temperatures reduce yields and quality, as in Himachal Pradesh (Vaidya et al., 2019). The rising temperatures and decreased snowfall have adversely affected apple cultivation. The unconducive weather during fruit setting and development in apples has reduced the apple productivity of the regions as in Himachal Pradesh (Singh et al., 2016). Notably, the apple orchards below 1500 m elevation have almost been rendered unproductive. Due to erratic temperatures, tomato plants' flowering and fruiting stages significantly reduce yield (Hazra et al., 2007). Higher temperatures also affect the color, size, and flavor of fruits, such as mangoes and bananas, which are important crops in India (Nath et al., 2019). The aberrations in weather like prolonged cloudy weather and rains during the full bloom hamper normal cross-pollination and fruit set in litchi (Kumar, 2012; Bal and Minhas, 2017).

The effect of climate change on vegetable production can be both direct and indirect (Bhardwaj, 2012). The direct effect of climate change on vegetable production in India includes changes in temperature and rainfall patterns, which affect crop growth and yield (Kumar, 2012; Bhardwaj, 2019). Higher temperatures during the growing season led to heat stress, lower photosynthetic rates, and lower yields. In addition, changes in rainfall patterns, such as erratic rains or droughts, result in water stress, affecting crop growth and yield (Naik et al., 2017). The indirect effects of climate change on vegetable production in India are linked to increased pest and disease incidence (Koundinya et al., 2018). Warmer temperatures lead to a higher incidence of pests and diseases, reducing yields and produce quality. Changes in temperature and precipitation also alter the timing of pest and disease outbreaks, making it difficult for farmers to predict and manage them effectively. In addition to the direct and indirect effects of climate change, vegetable production in Bihar is also affected by changes in soil fertility and quality (Solankey et al., 2019). Changes in temperature and precipitation patterns lead to soil nutrient availability and moisture content changes (Parajuli et al., 2019). Climate change also increases the frequency and intensity of extreme weather events, such as cyclones, storms, and floods, which devastate fruit and vegetable production in the affected regions. These events damage crops, disrupt supply chains, and cause price fluctuations in the market (Rao et al., 2016). For example, the severe cyclone *Amphan* that hit the eastern coast of West Bengal in 2020 caused significant damage to fruit and vegetable crops in the region (Mondal et al., 2021).

A.3 Effect on Livestock Production

The effects of climate change on food production extend beyond food crops. It affects food security in direct or indirect ways, through other subcomponents of the agricultural production systems, such as livestock production, which is closely linked with crop production. The relationships between livestock populations and the environment are complex. There are many ways in which climate change may affect the livestock production system. Following, we discuss the effects of climate change in three different sections: the effect on large ruminants, the effect on small ruminants, and the effect on poultry.

A.3.1 Effect on Large Ruminants

Climate change has significant implications for the livestock sector in India, particularly for large ruminants such as cattle and buffalo. The changes in temperature, rainfall patterns, temperature-humidity index, and availability of water and forage significantly affect the productivity and health of these animals, as observed in studies in Andhra Pradesh, Maharashtra, Karnataka, Tamil Nadu, and Haryana (Kumar et al., 2015; Sheikh et al., 2017).

High temperatures lead to heat stress, which causes reduced feed intake, lower productivity, and increased mortality (Sirohi and Michaelowa, 2007; Chauhan and Ghosh, 2014). Moreover, heat stress reduces milk production of cattle and buffalo by up to 50 % (Sheikh et al., 2017; Thorat et al., 2016; Dhaliwal et al., 2021). Similarly, thermal stress decreases milk yield and quality in buffaloes (Marai and Haeeb, 2010). Additionally, heat stress reduces the fertility of cows and buffaloes, resulting in lower reproductive efficiency and increased calving intervals (Das, 2017). The impact was more significant on hybrid cows than on local breed cows like Deoni and Sahiwal cows in Maharashtra (Das and Singh, 2016).

Fluctuations in rainfall patterns and the availability of water and forage significantly affect large ruminants in India (Saxena et al., 2020; Singh et al., 2021a, 2021b, 2021c). As temperatures rise, the growth and quality of vegetation are adversely affected, leading to a decline in the availability of nutritious feed for animals (Balhara et al., 2017; Malik et al., 2015). This in turn results in lower productivity of feed and increased susceptibility to diseases. Variations in forage availability also affect the nutritional status of animals, making them more susceptible to heat stress and other environmental challenges (Giridhar and Samireddypalle, 2015).

Climate change also contributes to increased incidence of diseases in large ruminants. For example, the prevalence of tick-borne diseases such as babesiosis and anaplasmosis increases as temperature increases, as indicated by a research study in Haryana (Ganguly et al., 2017). Similarly, fungal infections such as dermatophytosis and ringworm become more widespread with elevated levels of humidity and rainfall (Gupta and Mondal, 2021; Gautam et al., 2021). These diseases lead to decreased productivity and increased occurrence of animal mortality and morbidity.

A.3.2 Effect on Small Ruminants

Climate change is a growing concern also for small ruminants, such as sheep and goats production in India, as it poses several risks to the health and productivity of these animals; however, they have better adaptability to climate variation compared to large ruminants (Biradar et al., 2012; Gupta and Mondal, 2021).

In India, heat stress is a widespread problem for small ruminants, often raised under open grazing systems in common and temporary fallow lands (Younis and Khidr, 2020). Heat stress significantly reduces the reproductive performance of small ruminants, leading to reduced conception rates and increased embryonic mortality (Gupta and Mondal, 2021; Shinde and Sejian, 2013). High temperatures and humidity levels lead to heat stress in small ruminants, resulting in reduced fertility, increased embryonic mortality, and reduced milk production (Shinde and Sejian, 2013; Sejian et al., 2019).

Another major effect of climate change on small ruminant production in India is reduced feed and water availability. Studies have shown that climate change has led to increased drought conditions and irregular rainfall patterns, reducing the availability and quality of forage and water resources especially from common pool resources for small ruminants in India. This has decreased the milk productivity and reproductive efficiency of small ruminants, especially in India's arid and semi-arid regions, where water sources are often of poor quality, as observed in the states of Jammu and Kashmir, Himachal Pradesh, Rajasthan, Gujarat, Odisha, West Bengal and Telangana (Shinde and Sejian, 2013).

Climate change also increases the incidence and severity of infectious diseases that affect small ruminants in Rajasthan (Sonawane et al., 2012). Changes in temperature and humidity patterns create favorable conditions for the survival and transmission of infectious agents. Tick-borne diseases, such as anaplasmosis, babesiosis, and theileriosis, are becoming more prevalent in India due to climate change. The prevalence of tick-borne diseases in small ruminants in India is increasing, leading to economic losses for farmers (Ghosh et al., 2006).

A.3.3 Effect on Poultry

Climate change has both direct and indirect effects on poultry birds. The direct effect is the one that affects the poultry, either through an erratic increase or decrease in temperature, humidity, and precipitation. However, heat stress is the most important climatic factor adversely affecting poultry performance (Rao et al., 2016). Different haemato-biochemical parameters for heat stress-related traits were significantly higher during higher stress conditions in Odisha (Sahoo et al., 2022). Higher temperatures during the summer months lead to heat stress in poultry birds, which causes a decrease in feed intake and ultimately reduces egg production (GSLHV Prasada Rao, 2017; Aswathi et al., 2019) and also affect the shape of the eggs based on studies in Odisha and Uttar Pradesh (Nayak et al., 2015; Aswathi et al., 2019). As evident from research in Punjab, heat stress also increases the time from their pre-pubertal stage to puberty, which delays egg production (Sharma et al., 2022). Moreover, heat stress causes an increase in the level of liver enzymes in serum which could be correlated with a higher mortality rate, as observed in Odisha (Sahoo et al., 2022).

The indirect effects include the lack of enabling environment through the increase of pests/ diseases and reduction in the quality of feed with the change in the climate parameters such as temperature and precipitation that can affect the health of poultry. Warmer temperatures and precipitation patterns lead to changes in the distribution and abundance of pests and diseases, severely affecting the poultry industry. Changes in temperature and precipitation also affect the breeding patterns of pests and diseases, leading to a higher incidence of outbreaks (GSLHV Prasada Rao, 2017).

In addition to the direct and indirect effects, changes in temperature and precipitation patterns lead to changes in the availability of feed ingredients, which affect the quality and nutritional value of the feed. This has implications for the growth and development of poultry birds and ultimately affects their productivity (GoI Report, 2015).

A.4. Effect on Aquaculture Production

Aquaculture is an important economic sector in India, providing a significant source of food, income, and employment. However, the industry is vulnerable to climate change's effects, including temperature changes, precipitation, and extreme weather events (Priyadarshi et al., 2019; Mohanty et al., 2010). Climate change threatens fisheries resources and fish production, as observed in Jammu and Kashmir, Himachal Pradesh, Punjab, and Kerala (Sarkar and Borah, 2018). As a result, the diversity of species is decreasing slowly due to sudden changes in the environment. This reduction in the fish population has many effects. As the fish population is decreasing, it directly or indirectly affects those people who are dependent on the fisheries.

Temperature is a key factor in the growth and survival of aquatic species. Studies in Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha, West Bengal, and Assam indicated that rising temperatures due to climate change leads to changes in the distribution and abundance of species and their growth rates and reproduction (Vivekanandan, 2013; Vass et al., 2009; Saud et al., 2012). In freshwater systems, warming temperatures increase the incidence of diseases and parasites, particularly in farmed species such as catfish and tilapia (Simard, 2010). Increasing water temperature enhances some fish species' growth and reproductive activity, such as the common carp and tilapia (Simard, 2010; Sarkar et al., 2020). On the other hand, high temperatures also lead to stress, reduced oxygen levels, and increased susceptibility to disease, negatively affecting fish and shrimp production (Simard, 2010). In coastal systems, warming temperatures change the timing and abundance of phytoplankton blooms, affecting shellfish and finfish species' food availability and growth rates (Simard, 2010; Punya et al., 2021).

Climate change is expected to alter precipitation patterns in India, which could negatively affect aquaculture production. For instance, changes in rainfall patterns alter water availability, affecting the growth and survival of aquatic organisms (Simard, 2010; Sahoo et al., 2021). Heavy rainfall also causes flooding, leading to stock loss and infrastructure damage (Simard, 2010). Conversely, in West Bengal, droughts resulting from decreased precipitation led to water scarcity, negatively affecting aquaculture production (Biswas, 2019). Drought conditions reduce water levels and increase salinity, harming many freshwater species in Assam (Bhattacharjya et al., 2021). Conversely, heavy precipitation events lead to flooding and the release of pollutants, which also affects the health of aquatic species, as evident from the study in Maharashtra, Andhra Pradesh, Madhya Pradesh, Karnataka, Chattisgarh, and Odisha (Panikkar et al., 2022). In coastal systems, changes in precipitation lead to changes in the amount and timing of freshwater inflows, which affect the salinity and nutrient levels of estuaries and coastal waters, affecting the growth and reproduction of species (Martin et al., 2008).

Extreme weather events such as cyclones, storm surges, and floods also negatively affect aquaculture production in India (Makwana and Patnaik, 2021; Bhattacharjya et al., 2021). Such events cause damage to aquaculture infrastructure, loss of stock, and contamination of water bodies (Abisha et al., 2022). Additionally, extreme weather events cause water quality and temperature changes, leading to mortality or reduced growth of aquatic organisms (Ruby and Ahilan, 2018). For example, the 2004 Tsunami in Andaman resulted in the loss of fishery resources on the Andaman coast, indicating that those resources had, in some areas, declined by half after the tsunami, leading to economic losses for farmers (Muralidhar et al., 2012; Morner, 2011). In the coastal systems of West Bengal, cyclones cause significant damage to aquaculture farms and infrastructure, resulting in economic losses and reduced production (Dubey et al., 2017). Inland floods also lead to significant losses, particularly in low-lying areas where fish farms may be inundated with water or damaged by debris (Morner, 2011; Dubey et al., 2017).

B. Climate change effects on Access to Food

Access to food is usually defined as the ability to obtain food, including purchasing food at affordable prices (Mbow et al., 2019). The effects of climate change on access to food have been discussed with three dimensions: the effect of price and risk of hunger, the effect on land use, and the effect on storage.

B.1 Effect on Prices and Risk of Hunger

In India, most of the small and marginal farmers rely on rain-fed cropping systems, which provide barely a few months of food security in a normal year (Ramachandran, 2014). The increasing frequency of extreme weather events such as droughts, floods, storms, and rising temperatures leads to reduced crop yields, reduced livestock productivity, and declining fish stocks (Swaminathan and Kesavan, 2012). This decline in food production has two spillover effects. As seen in Maharashtra, the first step reduces the farmer's income (Vedeld et al., 2014). This fall in income is expected to significantly affect households' consumption, especially for women and children, as families with low financial resources usually allocate most of their income towards food expenses. Moreover, in the second stage, this decline in food availability increases food costs, affecting consumers through higher prices and reduced purchasing power (Kar and Das, 2015). This reduction in purchasing power either reduces the energy intake (calories) or shifts towards less nutritive food which can have serious health consequences, especially for children (Ritchie et al., 2018; Swaminathan et al., 2013; Aleksandrowicz et al., 2019; Noushadali, 2021).

The impact of climate change on food accessibility extends beyond rural regions and urban areas. Climate change adversely affects agriculture, exacerbating the vulnerability of marginalized rural populations who rely on farming. For example, in Maharashtra, New Delhi, Bihar, and Jharkhand, climate change acts as a trigger for individuals to migrate in search of better living conditions and alternative sources of income (Hari et al., 2021; Jha et al., 2018; Bhatta and Aggarwal, 2016; Viswanathan and Kumar, 2015; Ghosh-Jerath et al., 2021). Most of these migrants tend to become part of the poorly compensated workforce within the informal sector of urban areas (Ramachandran, 2014). This falls into the further trap of poverty and hunger, leading to poor health and nutritional status, and neglect of their children's health and education as seen in Karnataka (Bhor and Kumar, 2016).

B.2 Effect on Land Use

Climate change affects land use in agriculture through various channels. High temperatures lead to reduced crop yields, although the degree of impact varies by crop type. The differences in crop yield response to temperature influence farmers' choices regarding land allocation (Birthal et al., 2021).

There are some pieces of evidence that Indian farmers from Odisha, West Bengal, and Telangana are shifting from major food grain crops to legumes and minor cereal crops or non-food grain crops due to climate change (Sabar and Midya, 2022; Paria et al., 2022; Kondabolu, 2014). It is also found that farmers are shifting from water-intensive crops such as rice to less water-intensive crops such as maize and pulses in response to declining water availability in semi-arid areas of India (Shiferaw et al., 2008; Dhanya and Ramachandran, 2016). Similarly, farmers in Gujarat are shifting from food grain crops to cotton and sugarcane due to water shortages and declining food grain crops (Mathur and Kashyap, 2000). It was also found that in Telangana, the cropping systems in the recent period show considerably reduced cropping diversity compared to the previous period (Kondabolu, 2014). In certain regions of Himachal Pradesh, there has been a shift in the apple-growing belt towards higher altitudes. This has replaced former apple production areas with vegetable cultivation (Rana et al., 2013).

B.3 Effect on Storage

Climate change has significantly affected food stocks in India, affecting the quantity and quality of stored grain. Temperature changes, precipitation patterns, and extreme weather events are some of the factors that contribute to the effect.

The studies from Punjab, Madhya Pradesh, Haryana, and West Bengal found that during storage, insects pose a significant threat to causing post-harvest losses in stored food grains, resulting in both qualitative and quantitative losses in cereals, legumes, and oilseeds (Guru and Mridula, 2021; Banga et al., 2020; Das et al., 2020). Higher temperatures have increased insect infestation in stored grain. Higher temperatures also increase the metabolic rate of pests, resulting in faster reproduction rates and more damage to stored grains (Deka et al., 2009).

Changes in precipitation patterns have also affected food storage. Higher moisture levels in the air lead to fungal growth and insect infestation in stored grains (Mohapatra et al., 2017). Increased and unseasonal rainfall also led to flooding, damaging storage facilities and resulting in stored grains loss (Reddy and Reddy, 2015).

Climate change has led to higher frequency and severity of extreme weather events such as floods, cyclones, and droughts. These events damage the storage infrastructure, resulting in the loss of stored grain, as seen in Gujarat (Douglas, 2009). Cyclone Fani, which hit India's east coast in 2019, damaged storage facilities and caused a loss of stored grains in Odisha (Nandi et al., 2020).

C. Climate Change Effect on Food Utilization

Food utilization comprises the nutrient composition of food, its preparation, and its effect on health (Mbow et al., 2019; Kumar et al., 2022). The food utilization is directly affected by food safety and quality (Magan et al., 2011). Therefore, the effect of climate change on food utilization is bifurcated into the following two dimensions: The effect on Food Safety and Human Health, and the Effect on Food Quality.

C.1 Effect on Food Safety and Human Health

Climate change significantly affects India's food safety and human health (Lakshminarayanan, 2011; Change, 2020 Ghosh-Jerath et al., 2021). Changes in temperature and precipitation patterns and extreme weather events have been observed to affect the growth and spread of pathogenic microorganisms in food and water, leading to foodborne illnesses in Karnataka, Tamil Nadu, and Kashmir (Priyanka et al., 2016; Dhanashree and Mallya, 2008; GOI, 2017; Mertens et al., 2019; Ishtiyak et al., 2016). Moreover, increasing temperatures also affect the behavior of insect pests that damage crops, leading to increased use of pesticides, which leads to the contamination of food products and finally affects human health (Sharma, 2014; Sarkar et al., 2021a, 2021b; Chourasiya et al., 2015; Shetty, 2004).

In addition to enteric pathogens, changes in temperature and humidity due to climate change affect the growth and activity of mycotoxin-producing fungi, which contaminate crops and threaten human health (Chatterjee et al., 2022). Aflatoxins, in particular, are a major concern due to their carcinogenic properties and widespread occurrence in crops such as maize, groundnuts, and spices. Rising temperatures and changes in rainfall patterns increase the growth of aflatoxin-producing fungi in crops, while changes in storage conditions also lead to increased contamination (Reddy and Raghavender, 2007; Wenndt et al., 2020; Shekhar et al., 2018).

C.2 Effect on Food Quality

Food quality may get affected through two primary mechanisms in response to climate change (Mbow et al., 2019). The first mechanism directly affects plant and animal biology, such as temperature changes that alter plants' basic metabolic processes. The second mechanism involves the effect of increased carbon dioxide levels on biology through CO2 fertilization.

C.2.1 Direct Effect on Plant and Animal Biology

The effects of climate change on plant and animal biology in India have significant implications for food security, ecosystem services, and human health. Climate has an impact on a variety of biological processes, such as the metabolic rate of plants and animals. These processes play a significant role in determining growth rates and, ultimately, crop yields. Altering these processes changes the growth rates and, therefore, the overall yield.

Changes in plant phenology affect crop yields and food security, while changes in animal biology affect ecosystem services such as pollination and pest control, as seen in Uttar Pradesh (Sharma, 2014). Climate change has affected plant biology by altering the timing of phenological events such as flowering and fruiting, which are essential for the growth and reproduction of plants (Ramírez and Kallarackal, 2018). The changes in rainfall and temperature patterns have resulted in the early onset of spring, which disrupts the synchronicity between flowering and pollination, leading to a decline in the population of pollinators such as bees and butterflies based on the studies in Karnataka and Himachal Pradesh (Rupa et al., 2013; Singh, 2013; Abrol, 2012; Vedwan and Rhoades, 2001; Mukherjee et al., 2019a, 2019b). Additionally, the increase in temperature in Himachal Pradesh and Uttar Pradesh has led to the loss of biodiversity in forests, with many plant species unable to adapt to the changing climate (Kumar and Chopra, 2009; Sharma et al., 2011).

Studies based in New Delhi showed that diurnal temperature and radiation change effects negatively on yield quality of aromatic rice cultivars (Johnson et al., 2011; Nagarajan et al., 2010). High temperatures in New Delhi, Telangana, and Uttar Pradesh, explicitly in the reproductive phase, are extremely deleterious, causing flower abortion and abnormal pod filling of legumes (Dutta et al., 2022).

The effects of climate change on animal biology have also been significant. In Haryana, changes in temperature and rainfall patterns have altered animal breeding patterns (Singh et al., 2021a, 2021b, 2021c). The increase in temperature has also led to new animal diseases (Yadav et al., 2020; GoI Annual Report, 2019; 2021; 2022).

C.2.2 Effect of Rising CO2 Concentrations

Over the past twenty years, the global concentrations of greenhouse gases (GHGs), including carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and tropospheric ozone (referred to as O3), have seen a substantial increase. Of these GHGs, CO2 and O3 strongly correlate with the growth, yield, and quality of grains like wheat, rice, maize, and chickpea, as observed in the states of New Delhi, Telangana, and Uttar Pradesh (Dutta et al., 2022; Saha et al., 2015). Increasing CO2 concentration decreases the protein and micronutrient content of India's wheat, rice, and legume crops (Myers et al., 2014; Lamichaney et al., 2021; Pal et al., 2008). It was found that the combined effects of elevated CO2 concentrations and heat stress decrease the protein content of rice in New Delhi (Chaturvedi et al., 2017). These nutrients are essential for human health, and the decline in crop availability due to rising CO2 concentrations could significantly affect the health of people who rely on them as a major source of nutrition in India.

D. Climate Change effect on Food Stability

Food stability means people can access and use food steadily, so there are no intervening periods of hunger (Mbow et al., 2019). Increasing extreme events associated with climate change disrupt food stability.

D.1 Effect of Extreme Events

Climate change-induced extreme events, such as floods, droughts, and heat waves, significantly affect food security and nutrition in India.

These events often lead to crop failures, food shortages, and increases in food prices, resulting in reduced access to food for the poor and vulnerable sections of society (Swaminathan and Rengalakshmi, 2016; Ray et al., 2019; Srivastava and Mehta, 2018). Extreme weather events, such as floods and droughts, in the states of Tamil Nadu, Bihar, Telangana, and Karnataka lead to significant crop losses, resulting in decreased food availability and increased prices, disproportionately affecting low-income populations (Vishnu and Sridharan, 2016; Kumar et al., 2016; Samuel et al., 2021; Suresh and Dinesh, 2015). Moreover, these events also lead to supply chain disruptions, affecting food product distribution and food insecurity, as observed in the studies in Tamil Nadu, Odisha, and Bihar (Vishnu and Sridharan, 2016; Sam et al., 2021; Kumar et al., 2016;). Various studies conducted in India have documented the adverse effects of extreme weather events on food security and nutrition (Vishnu and Sridharan, 2016; Nath, 2022). For example, the 2018 floods in Kerala caused widespread damage to crops, livestock, and food storage facilities, leading to food shortages and price hikes leading to an increase in malnutrition and health problems (Veerakumaran and Santhi, 2019; Vani and Joseph, 2020; Dimitrova and Muttarak, 2020). It was also found that vulnerability in agriculture affects child nutrition (Mahapatra et al., 2021).

In addition to the effect on food production and distribution, extreme weather events indirectly affect food security and nutrition through effects on livelihoods (Rehman et al., 2022) and incomes (Parida, 2017; Udmale et al., 2014). Agricultural workers, who are already vulnerable to food insecurity, may lose their livelihoods as a result of crop losses (Veerakumaran and Santhi, 2019; Chowdhury et al., 2022; Rahman and Barman, 2019; Parida, 2017). Furthermore, climate change may exacerbate existing inequalities and lead to the displacement of marginalized communities, as in Bihar, leading to increased food insecurity and malnutrition (Somanathan and Somanathan, 2009). Extreme events due to climate change in the states of Andhra Pradesh, West Bengal, Maharashtra, and Kerala have been damaging the livelihoods of aquaculture producers (Shyam et al., 2014; Salagrama, 2013).

In addition to the crop sector, the livestock and other allied sectors are also confronted with several issues, such as poor health, scarcity of feed and fodder, high occurrences of emerging and re-emerging diseases, and mortality resulting from extreme events like droughts and floods (Rasool et al., 2021; GoI Report, 2015). These issues are contributing to the shortage of food.

D.2 Effect on Distribution of Food Aid

The efficient distribution of food aid to vulnerable communities relies on complex logistics, transportation, and storage systems. These systems are sensitive to severe weather events, such as road closures due to flooding or damage to storages due to high winds. These challenges resulted in delays in the timely distribution of food aid and in the loss of perishable food items.

The effect of climate change on food aid distribution was studied in different Indian states. The research study from Andhra Pradesh indicated that extreme weather events, such as cyclones and floods, had disrupted the supply chain and storage facilities, causing significant delays and losses in food aid distribution (Ramakrishna et al., 2014).

The effect of climate change on food aid distribution particularly in the context of child nutrition, in the states of Odisha, Tamil Nadu, West Bengal, and Andhra Pradesh, was also studied (Rodriguez-Llanes et al., 2011; Bartlett, 2008). The research study found that extreme weather events have reduced access to nutritious foods, severely affecting children's nutritional status (Algur et al., 2021; Bartlett, 2008). However, limited number of studies have been conducted on the effect of climate change on food aid distribution in India.

5. Discussion

This systematic review examines the multifaceted impacts of climate change on food security and nutrition in India, focusing on four dimensions: food availability, food access, food utilization, and food stability. The findings highlight the complexity and interconnectedness of these concepts and the critical importance of appropriately designing and implementing policies to mitigate the negative impacts of climate change.

Food production and supply of food have been reported to be severely affected by climate change in India. Rising temperatures, erratic rainfall, and the increasing frequency of extreme weather events, such as floods and droughts, have led to significant declines in crop yields, rice by 10–40 %, wheat and maize by 2–12 %, and sorghum by 10–12 %. Extreme weather events, such as droughts and heat waves, have particularly been detrimental, reducing chickpea production by up to 45 % and significantly affecting oilseed crops like sunflower. Climate change not only affects the agricultural sector but also its allied sectors. Heat stress was reported to result in a reduction in milk production from cattle and buffalo by up to 50 % in certain regions. The availability of fish species also changed due to rising temperatures, affecting their growth and reproduction and thereby threatening the availability of protein sources. These disruptions emphasize the urgent need to adopt climate-resilient farming practices and diversify agricultural systems to ensure long-term food availability.

Food accessibility has been another critical dimension influenced by climate change. The disruption of food production systems due to extreme weather events drives food price inflation, disproportionately affecting low-income and vulnerable populations. As food becomes more expensive, the purchasing power of marginalized communities' declines, leading to increased food insecurity. Additionally, the review highlights that climate-induced displacement of rural populations further exacerbates food accessibility issues. Migrants often face challenges in securing stable employment and affordable food in urban areas, placing them at heightened risk of hunger and malnutrition. These findings point to the need for inclusive policies that address both rural and urban food accessibility challenges and ensure that vulnerable groups have adequate access to affordable, nutritious food.

Food utilization, which refers to the nutritional quality and safety of food, was also reported to be negatively impacted due to climate change and extremes. Higher levels of CO_2 in experimental studies have shown to reduce the nutritional content of major crops such as rice, wheat, and legumes, which would lead to lower levels of essential nutrients like protein and micronutrients. This poses significant health risks, particularly for populations that rely heavily on these crops as their primary food sources. In addition, climate change and variability promoted the proliferation of pests and pathogens, increasing the risk of foodborne illnesses and contaminations that further compromise food safety. These issues highlight the need for strategies to enhance food quality and safety, including efforts to biofortify crops and improve food storage practices to reduce post-harvest losses.

Food stability has increasingly been threatened by the unpredictable nature of extreme weather events, such as floods, droughts, and heat waves, which disrupt food supply chains and cause localized food shortages. The instability in food production and distribution creates price volatility, making it difficult for vulnerable communities to maintain consistent access to food. Moreover, we point out that these disruptions are often most severe in regions that are already prone to natural disasters, exacerbating existing inequalities in food security. Strengthening disaster awareness and forewarning, improving food aid distribution based on seasonal climate forecasts, and investing in resilient infrastructure are important to ensuring food stability in the face of climate change.

Although significant progress has been made in understanding the impact of climate change on food security and nutrition in India, however, critical evidence gaps remain. Addressing these gaps is essential for developing comprehensive strategies to adapt and mitigate the adverse effects of climate change on agriculture and food systems, ensuring sustainable food security for the country.

The impact of climate change on crop productivity has been studied extensively for major staples like rice and wheat, but there is limited research on dryland crops such as millets and sorghum. These crops, which are more resilient to climate stressors like drought and heat, hold potential for strengthening food security in vulnerable regions. However, their nutritional value, productivity under changing climate conditions, and their role in marginal and tribal communities remain underexplored. More research is needed to assess the long-term viability of these crops, particularly for smallholder farmers who rely on them for both food and income.

While significant research has been conducted on staple crops, there is a lack of studies on how climate change affects indigenous and traditional food systems, particularly in tribal and remote areas. Understanding how these systems adapt to climate variability, and their role in sustaining food security, needs further investigation.

There is a growing recognition of the role of urban agriculture and localized food systems in improving food security. However, research on how these systems can be leveraged to mitigate climate-induced food shortages remains inadequate.

Research has focused on crop production losses due to climate change, but less attention has been given to post-harvest losses. Extreme weather events such as heatwaves and excessive humidity can accelerate spoilage, increase storage losses, and contribute to food waste. Future studies should evaluate the effectiveness of climate-resilient storage infrastructure and cost-effective waste reduction strategies.

There is also a lack of evidence on the long-term effects of climate change on soil health. Climate change is expected to alter soil fertility and nutrient availability, affecting crop productivity. However, studies examining the resilience of agricultural systems and their ability to adapt to changes in soil conditions are limited. Not much evidence is available on the climate change effect on soil microbes and harnessing their role for adaptation. Research focusing on soil health in different agro-climatic zones is necessary to design strategies that improve nutrient management and enhance the resilience of farming systems.

While the impact of climate change on water availability for irrigation has been explored, its cascading effects on food production and nutrition remain under-researched. There is a need for studies linking water scarcity with shifts in dietary patterns, micronutrient deficiencies, and food affordability.

Livestock performance under changing climate is another area where evidence is scarce. While the negative impacts of climate change on large ruminants, such as heat stress under high humidity reducing milk production, are well-documented, there is limited research on the impacts of climate variability across different species and regions. The performance of livestock under varying climatic conditions, particularly in regions that rely heavily on pastoralism and mixed farming systems, needs more attention. This is critical for designing adaptive measures that can safeguard livestock production, a major source of income and nutrition in many parts of India and several other countries in Asia and Africa.

The review also highlights the need for research on the effects of climate change on agricultural biodiversity, including the role of pollinators like honeybees. Climate change can disrupt the pollination function essential for many crops, yet little is known about how changing temperatures and weather patterns impact pollinator populations and their interactions with crops. A deeper understanding of these dynamics is critical for maintaining crop productivity and biodiversity in agricultural landscapes.

Furthermore, there is insufficient data and understanding of the effect of climate change and availability on nutritional content and quality of food products. Rising CO2 levels, temperature, and other climate factors are likely to affect the nutrient composition of food crops, yet this area remains under-researched. Given the importance of micronutrient-rich crops for combating malnutrition, especially among vulnerable populations, more focused research is needed on how climate change influences the nutritional quality of food products.

The impact of climate change on food utilization is another dimension requiring more research. There is limited understanding of how climate change affects food safety and human health, particularly in relation to foodborne diseases and contamination. Rising temperatures and changes in precipitation patterns can increase the prevalence of pathogens, which in turn affects food safety. Additionally, the use of pesticides and fertilizers, exacerbated by changing climate conditions, can lead to contamination that impacts human health. These are areas that need robust, targeted studies to understand the pathways through which climate change impacts food utilization.

The effects of climate change on food distribution systems and price volatility are also under-researched. While there is evidence that extreme weather events disrupt food supply chains, further investigation is needed into how these disruptions affect access to food, particularly for low-income populations. More research is needed to explore the potential for urban agriculture and local food systems to strengthen resilience and mitigate food price fluctuations in urban areas.

The socio-psychological impact of food insecurity due to climate change remains an underexplored area. Research should investigate the mental health effects on farming communities, urban low-income households, and displaced populations affected by climate-induced food shortages.

Increased frequency and intensity of heat waves and cold waves are likely to reduce working days, affect the health of farm workers, and increase the cost of labor. Generating evidence on these aspects will help in better adaptation policies.

The impact of climate change on food supply chains has been explored, but there is limited research on how small and medium food enterprises (SMEs) adapt to climate shocks. SMEs play a crucial role in food processing and distribution, and studies should assess their vulnerabilities and resilience strategies.

Finally, the socio-economic and political dimensions of climate change and food security require more attention. Climate change is not just an environmental issue; it has far-reaching social, economic, and governance implications. Issues such as gender equity, the role of traditional knowledge, and governance structures in managing food security under climate stress need further exploration to develop inclusive policies and programs that address the needs of marginalized populations. There are several research gaps, as discussed in this section above; however, the following areas require greater scientific attention. Dryland crops, such as millets and sorghum, offer climate resilience but remain under-researched in terms of agronomic performance, nutrition, and market integration. Post-harvest losses and climate-resilient storage systems need further study, as extreme weather accelerates spoilage and disrupts supply chains—cost-effective storage solutions and digital monitoring could help mitigate these losses. Nutritional content and food quality are also at risk, with rising CO_2 levels reducing protein and micronutrient content in staple crops, necessitating research on biofortification and soil health. Lastly, food distribution systems and price volatility require attention to prevent climate-induced disruptions that threaten accessibility and affordability. Further, most studies have been based on modeling, experimental trials, and secondary data; there is a need to generate more evidence at the household level on the effect of climate shocks on production, livelihoods, consumption, and well-being, as well as their adaptation strategies. Addressing these gaps is crucial for building a climate-resilient food system. While all the research gaps discussed require attention, these specific gaps demand urgent focus and immediate action to strengthen climate resilience in food systems.

6. Conclusions and policy implications

This review highlights substantial and multidimensional impacts of climate change on food security and nutrition in India. The findings emphasize how rising temperatures, changing precipitation patterns, and increased extreme weather events are driving reductions in crop productivity, livestock performance, aquaculture, and food safety.

However, the overall food production in the country remains largely stable due to the steady bridging of the existing yield gaps and adaptation measures with increased transaction costs. These impacts are felt disproportionately in different regions, with state-specific challenges emerging as key factors in food system vulnerabilities. Based on the evidence included in this paper, we propose the following policy recommendations—both national and state-specific—to holistically adapt to climate change impacts on food security. These policies must prioritize the most vulnerable agro-ecologies and populations, including smallholder farmers, women, and marginalized groups, ensuring just transitions.

- **Promoting Climate-Resilient Farming and Crop Diversification:** As climate change reduces crop productivity, particularly in rice-wheat systems in states like Punjab and Haryana, crop diversification is essential. The vulnerability of rainfed crops in states such as Odisha, Andhra Pradesh, and Tamil Nadu are also critical (Section 4, Subsection A1.1). Promote climate-resilient farming practices such as crop diversification, conservation agriculture, and agroforestry in vulnerable states. Support and mainstream production and consumption of resilient crops like millets and sorghum, etc. which are more drought tolerant and nutrition dense. Identifying suitable agroecology where these resilient crops may have a comparative advantage and policy support to address both supply and demand side challenges would be critical to promote diversification through these resilient crops. Lessons from India's crop diversification efforts can also be applied to other climate-vulnerable regions globally, particularly in South Asia and sub-Saharan Africa, where rainfed agriculture dominates. Sharing successful models of climate-resilient farming, such as India's National Mission for Sustainable Agriculture (NMSA) and National Innovations on Climate Resilient Agriculture (NICRA), can be helpful to other nations to develop localized strategies. Region-specific adaptation frameworks, capacity development, and sustainable business models for improving access to climate-resilient technologies will be key for their scaling. Additionally, policies must encourage and incentivize adaptive management of water resources to reduce over-reliance on irrigation for water-intensive crops such as rice, particularly in Punjab and Haryana.
- **Adapted Livestock Breeds and Strengthening Feed Systems:** Livestock in states such as Andhra Pradesh, Maharashtra, and Rajasthan are severely affected by heat stress, leading to reductions in milk production. Drought-induced feed shortages exacerbate the problem, especially in Rajasthan and Gujarat (Section 4, Subsection A3.1). Policies should prioritize investment in promoting high-yielding, climate adapted indigenous livestock breeds and improvement of feed and forage systems in drought-prone areas. Additionally, integrated crop-livestock systems should be promoted to ensure the availability of high-quality feed and enhance farm resilience, particularly in regions experiencing severe climatic stress. Strengthening research and extension programs for climate-resilient livestock management and ensuring access to affordable, nutrient-rich feed alternatives will be critical for sustaining livestock productivity under changing climatic conditions.
- **Strengthening Climate-Resilient Aquaculture Practices:** Aquaculture-dependent coastal regions, such as Kerala and West Bengal, face increasing risks due to rising water temperatures and extreme weather events (Section 4, Subsection A4). Policies should focus on developing adaptive aquaculture practices by promoting temperature-tolerant fish species, improving hatchery technologies, and enhancing water management infrastructure to sustain production under changing climatic conditions. Additionally, strengthen disaster preparedness and forewarning systems in coastal regions to protect aquaculture infrastructure from cyclones and floods. Special attention may be given to sustainable practices for small-scale fisheries, including climate-smart aquaculture techniques, diversification of income sources, and access to financial support for affected fishers. Expanding research on the impacts of climate change on marine and freshwater ecosystems and integrating aquaculture with coastal ecosystem restoration efforts can further enhance long-term sustainability and resilience.
- **Improving sustainable moisture availability for crops:** In many regions in India, farmers rely heavily on rainfall, making them vulnerable to variability in precipitation. States such as Rajasthan and Madhya Pradesh and other semiarid and arid regions are particularly impacted due to poor access to irrigation (Section 4, Subsection A1.3). Additionally, unsustainable use of available water for irrigation further exacerbates vulnerability to climate change by overexploiting the groundwater reserves. Policies should prioritize investment in rainwater harvesting systems, micro-irrigation technologies, and in-situ soil moisture conservation techniques to enhance water availability. These strategies should not only focus on arid and semi-arid rainfed regions but also on groundwater-dependent irrigated farming systems, where excessive water withdrawal threatens long-term sustainability. Strengthening climate-resilient water governance, expanding farmers' access to water-efficient technologies, and promoting integrated landscape management will be essential to mitigate the risk of crop failure due to irregular rainfall and ensure long-term agricultural resilience.
- **Ensuring Food Accessibility for Vulnerable Populations:** The increase in food prices due to climate-induced disruptions disproportionately affects low-income households, especially in states such as Bihar and Jharkhand, where food security remains precarious (Section 4, Subsection B1). Policies should expand targeted food subsidy programs by including nutrient-dense grains such as millets and pulses in the strengthened public distribution systems to improve dietary diversity and affordability to vulnerable populations, especially those in rural and low-income urban areas Additionally, implement price stabilization mechanisms, such as buffer stock management, market interventions, and localized procurement strategies, can help mitigate to prevent food price volatility during extreme weather events. Strengthening climate-resilient supply chains, improving storage and distribution infrastructure, and enhancing social safety nets will be critical to ensuring sustained food accessibility in the face of climate shocks.
- **Improving Nutritional Quality and Biofortification:** Climate change-induced reductions in the nutritional content of key crops, such as rice and wheat, threaten public health in multiple states, including Telangana, Uttar Pradesh, and Andhra Pradesh (Section 4, Subsection C2.2). Policies should promote biofortification of staple crops to enhance their nutritional content, with a particular focus on addressing micronutrient deficiencies such as iron, zinc, and vitamin A. Promoting integrated soil health management practices, including organic amendments, balanced fertilization, and crop rotation, is essential to maintain crop productivity, quality and food safety under changing climatic conditions. Additionally, biofortified crops should also be incorporated in public food programs such as mid-day meal schemes and public distribution systems to ensure broader access among nutritionally vulnerable populations. Expanding consumer awareness campaigns, incentivizing farmer adoption of biofortified varieties, and enhancing market linkages will further support the successful integration of biofortification into national food security strategies.
- **Strengthening Food Safety and Reducing Contamination Risks:** Climate change increases the risk of pest infestations and foodborne diseases, particularly reported in states like Karnataka, Tamil Nadu, and Kashmir, affecting food safety and security (Section 4, Subsection C1). Policies should strengthen food safety regulations, enhance monitoring systems for pesticide residues and contamination, and implement stricter enforcement mechanisms to protect public health. Expanding awareness programs for farmers and consumers on safe pesticide use, mycotoxin risks, and proper food handling is

essential. Leveraging digital technologies such as real-time contamination detection, blockchain-based traceability, and AI-driven monitoring systems can further enhance food quality surveillance. Additionally, developing pest-resistant crop varieties and investing in improved storage infrastructure at various scales, from household to commercial facilities, is crucial to minimize post-harvest losses and ensure that food remains safe for consumption.

- **Building Resilient Food Supply Chains and Disaster Preparedness:** Frequent disruptions to food supply chains due to extreme weather events such as floods and cyclones, especially in states like Bihar, Odisha, and West Bengal, among others resulting in localized food shortages and price volatility (Section 4, Subsection D1). Policies should strengthen disaster preparedness and forewarning early warning systems by improving weather forecasting, real-time monitoring, and rapid response mechanisms to minimize disruptions targeting all the stakeholders in the food value chains. Investing in climate-resilient infrastructure, including modern storage facilities, all weather transportation networks, and decentralized food distribution systems, is critical to maintaining supply chain stability. Additionally, developing district-level and sub-district-level agricultural contingency plans, especially in the climate hotspot regions, will help ensure immediate support for farmers and ensure food supply chain stability during crises. Enhancing public-private partnerships to improve logistics, supply chain efficiency, and food stock management will further contribute to long-term resilience against climate-induced disruptions.
- **Supporting Indigenous Food Systems and Urban Agriculture:** Indigenous food systems, which have historically adapted to environmental changes, are underutilized despite their potential to enhance food security and resilience. Similarly, urban agriculture in cities, especially metros, lacks appropriate policy support. Policies should promote the preservation, documentation, and integration of Indigenous food systems into broader agricultural policies, particularly in tribal regions like Jharkhand, Odisha, Chhattisgarh, and northeast states, among others. Strengthening value chains, market access, and knowledge-sharing platforms for Indigenous crops will encourage wider adoption and sustainability. Additionally, supporting research-backed urban agriculture initiatives in major cities can help to diversify food sources, lower transportation costs, and enhance access to fresh, nutrient-rich produce for urban populations.
- **Enhancing and Reorienting Agricultural Extension Services:** Farmers, especially smallholders in most of the states, often lack access to timely information and technical support on climate-resilient agricultural practices. Policies should strengthen and reorient agricultural extension services to provide localized, need-based guidance on climate-adaptive crop-livestock practices. Expanding the use of digital platforms, mobile advisory services, and AI-driven decision-support tools can enable near real-time dissemination of climate information, early warnings, and best practices to context-specific guidance to farmers and other stakeholders in the agricultural value chains. Additionally, fostering stronger collaboration between research institutions, extension agencies, and farmer organizations can enhance knowledge transfer, ensuring that smallholder farmers are well-equipped to adapt to climate challenges.
- **Addressing Gaps in Micro-Level Data and Localized Adaptation Strategies:** Most of the studies on the impact of climate change are based on modeling or macro-level secondary data, which limits the understanding of region-specific vulnerabilities. The lack of micro-level climate change impact assessments on smallholder farming systems, men and women, and the challenges faced by marginalized communities limits the effectiveness of policy responses. Policies should prioritize investments in micro-level research studies, and localized data collection to develop context-specific adaptation strategies. High-resolution, regionally disaggregated data is essential for designing targeted interventions that address the unique challenges of different regions, such as smallholder farmers in Uttar Pradesh and Bihar. Strengthening community-driven data collection mechanisms, integrating participatory research approaches, and leveraging digital technologies for near real-time situation assessment climate will be key to bridging existing knowledge gaps and enhancing climate resilience at the local level.
- **Addressing Socio-Economic Inequalities in Climate Adaptation:** Climate change exacerbates social and economic inequalities, particularly for women, children, and marginalized groups in several states, for example, as reported for Karnataka, Bihar, and Odisha (Section 4, Subsection D2). Policies should ensure that climate adaptation strategies are inclusive and equitable, prioritizing the needs and building capacities of marginalized communities. Implementing gender-sensitive programs that empower women through education, capacity building, access to climate-resilient resources, and financial support will enable them to play a central role in climate resilience efforts.
- **Promoting Research on Indigenous Knowledge and Traditional Crops:** The resilience of Indigenous crops and traditional agricultural knowledge in the face of climate change remains under-researched. Policies should prioritize research into high-potential indigenous crops and landraces and traditional farming knowledge to identify sustainable, climate-resilient practices that can be applied in regions facing severe climate impacts. This includes documenting and analyzing traditional cropping systems in states like Rajasthan and Gujarat, where such practices have historically mitigated the effects of drought and water scarcity. Strengthening collaborations between research institutions, Indigenous communities, and policymakers will be crucial to integrating traditional agricultural wisdom into modern climate adaptation strategies and scaling up climate-resilient farming models.
- **Expanding Renewable Energy Use in Agriculture:** The over-reliance on fossil fuels for irrigation and farming operations increases vulnerability to energy price fluctuations and climate impacts, particularly in rural agricultural areas. Policies should promote the adoption of renewable energy sources by implementing context-specific business models, such as solar-powered irrigation systems, biogas units, energy-efficient farming and post-harvest machinery. These technologies can reduce dependence on fossil fuels, lower greenhouse gas emissions, and increase energy security and resilience in rural agricultural areas. Strengthening financial incentives, technology access, and capacity-building programs will be crucial to accelerating the widespread adoption of renewable energy solutions in agriculture.

Looking ahead, the future of climate change and food security research should prioritize a more integrative and interdisciplinary approach that bridges environmental science, agriculture, nutrition, and socio-economic policy. Future studies should focus on strengthening climate-resilient food systems by promoting sustainable agricultural practices, including agroecology, regenerative farming, and climate-smart farming system diversification. The application of advanced technologies such as high resolution climate forecasting, precision agriculture, AI and remote sensing applications can enhance early warning systems and agro-advisories on adaptive strategies for smallholder farmers. Additionally, expanding research on alternative protein sources and biofortified crops can help address nutritional deficiencies in climate-stressed regions. Policymakers should also emphasize community-driven adaptation measures, strengthening local food systems, and ensuring equitable access to climate adaptation resources. In the near future, we expect to see stronger collaborations between governments, research institutions, and the private sector to develop innovative solutions that enhance food security while mitigating climate impacts. These efforts will be crucial in building resilient food systems that can withstand future climate uncertainties and ensure sustainable nutrition for vulnerable populations.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Appendix

Table 1
Inclusion and exclusion criteria.

Screening Phase	Criteria	Included	Excluded	Rationale
Title Screening	Topic relevance	Studies focused on climate change effects on food security, including availability, accessibility, utilization, and stability	Studies unrelated to food security and nutrition or not focused on climate change	Ensuring studies are directly relevant to the research question
Title & Abstract	Publication Type	Peer-reviewed articles, systematic reviews, significant grey literature from reputed bodies (e.g., FAO, UN, IPCC)	Conference abstracts, opinion pieces, editorials, meta-analyses without new empirical data	Ensuring inclusion of high-quality, data-driven studies
Abstract & Full Text	Study Scope	Studies assessing climate change's impact on food security (crop production, livestock, fisheries, food prices, nutritional quality, food stability) in India	Studies that do not focus on India or lack detailed analysis of food security dimensions	The focus is on India-specific evidence and key dimensions of food security
Full Text	Methodology & Data	Studies using quantitative or qualitative analysis, empirical studies, systematic reviews, and modeling approaches with robust actual data/ information.	Studies lacking methodological rigor, insufficient data for extraction, or speculative discussions	Ensuring reliability and reproducibility of findings
Inclusion Analysis	Outcomes Measured	Studies reporting impacts of climate change on food availability, accessibility, utilization, and stability, as well as adaptation strategies	Studies that do not provide clear evidence on how climate change affects food security and nutrition	Ensuring included studies contribute meaningfully to understanding the issue

Data availability

No data was used for the research described in the article.

References

Abisha, R., Krishnani, K.K., Sukhdhane, K., Verma, A.K., Brahmane, M., Chadha, N.K., 2022. Sustainable development of climate-resilient aquaculture and culture-based fisheries through adaptation of abiotic stresses: a review. J. Water Clim. Change 13 (7), 2671–2689.

Abrol, D.P., 2012. Pollination Biology: Biodiversity Conservation and Agricultural Production. Springer, New York.

Agrawal, K.K., Upadhyay, A.P., Jain, S., Bhadauria, U.P.S., 2009. Assessing the climate based productivity potential of soybean in Madhya Pradesh. J. Agrometeorol. 11 (2), 132–134.

Ahmad, J., Alam, D., Haseen, M.S., 2011. Impact of climate change on agriculture and food security in India. Int. J. Agric., Environ. Biotechnol. 4 (2), 129–137.

Ahmed, A., Deb, D., Mondal, S., 2019. Assessment of rainfall variability and its impact on groundnut yield in Bundelkhand region of India. Curr. Sci. 117 (5), 794–803.

Aleksandrowicz, L., Green, R., Joy, E.J., Harris, F., Hillier, J., Vetter, S.H., Haines, A., 2019. Environmental impacts of dietary shifts in India: a modelling study using nationally-representative data. Environ. Int. 126, 207–215.

Algur, K.D., Patel, S.K., Chauhan, S., 2021. The impact of drought on the health and livelihoods of women and children in India: a systematic review. Child Youth Serv. Rev. 122, 105909.

Arora, A., Bansal, S., Ward, P.S., 2019. Do farmers value rice varieties tolerant to droughts and floods? Evidence from a discrete choice experiment in Odisha, India. Water Resour. Econ. 25, 27–41.

Aryal, J.P., Jat, M.L., Sapkota, T.B., Rai, M., Jat, H.S., Sharma, P.C., Stirling, C., 2019. Learning adaptation to climate change from past climate extremes: Evidence from recent climate extremes in Haryana, India. Int. J. Climate Change Strategies Manage. 12 (1), 128–146.

Aswathi, P.B., Bhanja, S.K., Kumar, P., Shyamkumar, T.S., Mehra, M., Bhaisare, D.B., Rath, P.K., 2019. Effect of acute heat stress on the physiological and reproductive parameters of broiler breeder hens-a study under controlled thermal stress. Indian J. Animal Res. 53 (9), 1150–1155.

Bal, S.K., Minhas, P.S., 2017. Atmospheric stressors: challenges and coping strategies. In: Abiotic stress management for resilient agriculture, pp. 9–50.

Balhara, A., Nayan, V., Dey, A., Singh, K.P., Dahiya, S.S., Singh, I., 2017. Climate change and buffalo farming in major milk producing states of India-present status and need for addressing concerns. Indian J. Anim. Sci. 87 (4), 403–411.

Banga, K.S., Kumar, S., Kotwaliwale, N., Mohapatra, D., 2020. Major insects of stored food grains. Int. J. Chem. Stud. 8 (1), 2380–2384.

Bartlett, S., 2008. The implications of climate change for children in lower-income countries. Child. Youth Environ. 18 (1), 71–98.

Bhardwaj, M.L., 2012. Challenges and opportunities of vegetable cultivation under changing climate scenario. In: A training manual on vegetable production under changing climate scenario, pp. 13–18.

Bhardwaj, S.K., 2019. Impacts of climate Change/variability on phenology of vegetable crops: adaptation and mitigation strategy. In: Innovative Interventions for Sustainable Vegetable Production Under Changing Climate Scenario (3rd September to 23rd September 2019), 3, p. 125.

Bhardwaj, S.K., Sharma, S.D., 2012. Horticulture crop production in North-Western Himalayas under changing climate scenario. In: International Symposium for Agriculture and Food, XXXVII Faculty-Economy Meeting, IV Macedonian Symposium for Viticulture and Wine Production, VII Symposium for Vegetables and Flower Production, Skopje, Macedonia, 12-14 December 2012. Faculty of Agricultural Sciences and Food, University" Ss Cyril and Methodius", pp. 503–511.

Bhat, S.U., Pandit, A.K., 2020. Water quality assessment and monitoring of Kashmir Himalayan freshwater springs-a case study. Aquat. Ecosyst. Health Manag. 23 (3), 274–287.

Bhatta, G.D., Aggarwal, P.K., 2016. Coping with weather adversity and adaptation to climatic variability: a cross-country study of smallholder farmers in South Asia. Clim. Dev. 8 (2), 145–157.

Bhattacharjya, B.K., Yadav, A.K., Debnath, D., Saud, B.J., Verma, V.K., Yengkokpam, S., Das, B.K., 2021. Effect of extreme climatic events on fish seed production in lower Brahmaputra Valley, Assam, India: constraint analysis and adaptive strategies. Aquat. Ecosyst. Health Manag. 24 (3), 39–46.

Bhor, N., Kumar, P., 2016. Climate Change and Health: A Social Determinants Approach to Malnutrition among Migrant Children.

Biradar, N., Patil, S.L., Gajendra, T.H., Manjunath, L., 2012. Effect of climate of change on agriculture and livestock as perceived by the farmers of Karnataka. Int. J. Agric. Statist. Sci. 8, 251–258.

Birthal, P.S., Khan, T., Negi, D.S., Agarwal, S., 2014. Impact of climate change on yields of major food crops in India: implications for food security. Agric. Econ. Res. Rev. 27 (2), 145–155.

Birthal, P.S., Hazrana, J., Negi, D.S., Bhan, S.C., 2021. Climate change and land-use in Indian agriculture. Land Use Policy 109, 105652.

Biswas, A., 2019. Prevailing aquaculture practices in a drought-prone landscape: a case of Purulia district of West Bengal, India. Age 18 (30), 2–3.

Chakrabarty, M., 2016. Climate Change and Food Security in India. Observer Research Foundation (ORF), New Delhi, India, p. 157.
Chand, Shivani, Dhaliwal, Lakhvir, 2020. Analysis of intra-seasonal rainfall variability, number of rainy days and extreme rainfall events at different locations of Punjab. Agric. Res. J. 57, 536. https://doi.org/10.5958/2395-146X.2020.00078.2.
Chandio, A.A., Gokmenoglu, K.K., Ahmad, M., Jiang, Y., 2021. Towards sustainable rice production in Asia: the role of climatic factors. Earth Syst. Environ. 1–14.
Change, F.C., 2020. Unpacking the Burden on Food Safety. FAO—Food and Agriculture Organization of the United Nations, Rome, Italy.
Chatterjee, S., Dhole, A., Krishnan, A., Banerjee, K., 2022. Mycotoxin Monitoring, Regulation and Analysis in India: A Success Story.
Chaturvedi, A.K., Bahuguna, R.N., Pal, M., Shah, D., Maurya, S., Jagadish, K.S., 2017. Elevated CO2 and heat stress interactions affect grain yield, quality and mineral nutrient composition in rice under field conditions. Field Crop Res. 206, 149–157.
Chauhan, D.S., Ghosh, N., 2014. Impact of climate change on livestock production: a review. J. Animal Res. 4 (2), 223–239.
Chauhan, J.S., Tyagi, M.K., Kumar, A., Nashaat, N.I., Singh, M., Singh, N.B., Welham, S. J., 2007. Drought effects on yield and its components in Indian mustard (Brassica juncea L.). Plant Breed. 126 (4), 399–402.
Choudhary, K., Meena, A.K., Chand, K., Nain, Y., Maurya, S., 2022. Impact of epidemiological factors on the incidence of charcoal rot of Sesamum incited by Macrophomina phaseolina. *Biological forum – an.* Int. J. 14 (1), 264–268.
Chourasiya, S., Khillare, P.S., Jyethi, D.S., 2015. Health risk assessment of organochlorine pesticide exposure through dietary intake of vegetables grown in the periurban sites of Delhi, India. Environ. Sci. Pollut. Res. 22, 5793–5806.
Chowdhury, J.R., Parida, Y., Agarwal, P., 2022. How flood affects rural employment in India: a gender analysis. Int. J. Disaster Risk Red. 73, 102881.
Clapp, J., Moseley, W.G., Burlingame, B., Termine, P., 2022. The case for a six-dimensional food security framework. Food Policy 106, 102164.
Das, R., Biswas, S., Mandal, A.K., 2020. Quality parameters of sunflower (Helianthus annuus L.) seeds and seedlings under various storage duration and seed invigoration. Int. J. Curr. Microbiol. App. Sci. 9 (02), 76–87.
Das, S., 2017. Impact of climate change on livestock, various adaptive and mitigative measures for sustainable livestock production. Approaches Poultry, Dairy Vet. Sci. 1, 33.
Das, S.K., Singh, N.P., 2016. Effect of microclimatological changes on dairy cattle production under the coastal climate of Goa. Indian J. Animal Res. 50 (6), 1009–1012.
Datta, P., Behera, B., 2022. What caused smallholders to change farming practices in the era of climate change? Empirical evidence from sub-Himalayan West Bengal, India. GeoJournal 87 (5), 3621–3637.
Deka, S., Byjesh, K., Kumar, U., Choudhary, R., 2009. Climate change and impacts on crop pests-a critique. In: Workshop Proceedings: Impact of Climate Change on Agriculture, pp. 147–149.
Dhaliwal, R.K., Malhotra, P., Kashyap, N., Dash, S.K., Dhaliwal, L.K., Kaur, S., 2021. Determination of heat stress zone for daily milk yield using carryover heat effect model in Murrah buffaloes. Trop. Anim. Health Prod. 53 (5), 488.
Dhanashree, B., Mallya, P.S., 2008. Detection of Shiga-toxigenic Escherichia coli (STEC) in diarrhoeagenic stool & meat samples in Mangalore, India. Indian J. Med. Res. 128 (3), 271–277.
Dhanya, P., Ramachandran, A., 2016. Farmers' perceptions of climate change and the proposed agriculture adaptation strategies in a semi arid region of South India. J. Integr. Environ. Sci. 13 (1), 1–18.
Dimitrova, A., Muttarak, R., 2020. After the floods: differential impacts of rainfall anomalies on child stunting in India. Glob. Environ. Chang. 64.
Douglas, I., 2009. Climate change, flooding and food security in South Asia. Food Secur. 1, 127–136.
Dubey, S.K., Sah, U., Singh, S.K., 2011. Impact of climate change on pulse productivity and adaptation strategies as practiced by the pulse growers of Bundelkhand region of Uttar Pradesh. J. Food Legumes 24 (3), 230–234.
Dubey, S.K., Trivedi, R.K., Chand, B.K., Mandal, B., Rout, S.K., 2017. Farmers' perceptions of climate change, impacts on freshwater aquaculture and adaptation strategies in climatic change hotspots: a case of the Indian Sundarban delta. Environ. Develop. 21, 38–51.
Dutta, A., Trivedi, A., Nath, C.P., Gupta, D.S., Hazra, K.K., 2022. A comprehensive review on grain legumes as climate-smart crops: challenges and prospects. Environ. Challenges,7 ,100479,, 1–13.
Farooq, M., Nadeem, F., Gogoi, N., Ullah, A., Alghamdi, S.S., Nayyar, H., Siddique, K.H., 2017. Heat stress in grain legumes during reproductive and grain-filling phases. Crop Pasture Sci. 68 (11), 985–1005.
Food and Agriculture Organization, 2002. The State of Food Insecurity in the World 2001 (Food and Agriculture Organization, Rome).
Food and Agriculture Organization, 2006. The State of Food Insecurity in the World 2006 (Food and Agriculture Organization, Rome).
Ganguly, A., Bisla, R.S., Singh, H., Bhanot, V., Kumar, A., Kumari, S., Ganguly, I., 2017. Prevalence and haematobiochemical changes of tick borne haemoparasitic diseases in crossbred cattle of Haryana, India. Indian J. Animal Sci. 87 (5), 552–557.
Gautam, S.S., Babu, N., Kumar, S., 2021. Current perspective of dermatophytosis in animals. In: Fungal Diseases in Animals: From Infections to Prevention. Springer International Publishing, Cham, pp. 93–104.
Ghosh, S., Azhahianambi, P., de la Fuente, J., 2006. Control of ticks of ruminants, with special emphasis on livestock farming systems in India: present and future possibilities for integrated control—a review. Exp. Appl. Acarol. 40, 49–66.
Ghosh-Jerath, S., Kapoor, R., Ghosh, U., Singh, A., Downs, S., Fanzo, J., 2021. Pathways of climate change impact on agroforestry, food consumption pattern, and dietary diversity among indigenous subsistence farmers of Sauria Paharia tribal community of India: a mixed methods study. Front. Sustain. Food Syst. 5, 667297.
Giridhar, K., Samireddypalle, A., 2015. Impact of climate change on forage availability for livestock. In: Climate change impact on livestock: adaptation and mitigation, pp. 97–112.
GoI Annual Report, 2019. Department of animal husbandry and dairying ministry of fisheries. Animal Husbandry Dairying Government of India annual report 2018–2019.
GoI Annual Report, 2021. Department of Animal Husbandry and Dairying Ministry of fisheries. Animal Husbandry Dairying Government of India annual report 2020–2021.
GoI Annual Report, 2022. Department of Animal Husbandry and Dairying Ministry of fisheries. Animal Husbandry Dairying Government of India annual report 2021–2022.
GoI Report, 2015. Feed Ingredients for Ration for Livestock and Poultry.
Government of India, CD Alert, 2017. Monthly report, p. 16.
Gregory, P.J., Ingram, J.S., Brklacich, M., 2005. Climate change and food security. Philos. Trans. R. Soc. B 360 (1463), 2139–2148.
GSLHV Prasada Rao, 2017. Climate change: Adaptations of livestock, poultry and fisheries. In: Agriculture under Climate Change: Threats, Strategies and Policies, vol. 1. Allied Publishers, pp. 206–212.
Guntukula, R., 2020. Assessing the impact of climate change on Indian agriculture: evidence from major crop yields. J. Public Aff. 20 (1), e2040.
Guntukula, R., Goyari, P., 2020. The impact of climate change on maize yields and its variability in Telangana, India: a panel approach study. J. Public Aff. 20 (3), e2088.
Gupta, M., Mondal, T., 2021. Heat stress and thermoregulatory responses of goats: a review. Biol. Rhythm. Res. 52 (3), 407–433.
Guru, P.N., Mridula, D., 2021. Safe storage of food grains. In: ICAR-Central Institute of Post-Harvest Engineering and Technology, Ludhiana (Punjab). Technical Bulletin No.: ICAR-CIPHET/Pub./2021-22/01, p. 32.
Hari, V., Dharmasthala, S., Koppa, A., Karmakar, S., Kumar, R., 2021. Climate hazards are threatening vulnerable migrants in Indian megacities. Nat. Clim. Chang. 11 (8), 636–638.
Hazra, P., Samsul, H.A., Sikder, D., Peter, K.V., 2007. Breeding tomato (Lycopersicon esculentum mill) resistant to high temperature stress. Int. J. Plant Breed 1 (1), 31–40.
HLPE, 2020. Food Security and Nutrition: Building a Global Narrative Towards 2030. http://www.fao.org/3/ca9731en/ca9731en.pdf.
Ishtiyak, P., Reddy, M., Panse, S., Wani, I., Peer, Q.J.A., 2016. Impact of climate change and anthropogenic interventions on natural Vis-à-Vis human resources in Kashmir, India–an overview. J. Appl. Nat. Sci. 8 (1), 489–493.
Jha, C.K., Gupta, V., Chattopadhyay, U., Amarayil Sreeraman, B., 2018. Migration as adaptation strategy to cope with climate change: a study of farmers' migration in rural India. Int. J. Climate Change Strategies Manage. 10 (1), 121–141.
Jha, R.K., Kalita, P.K., Cooke, R.A., 2021. Assessment of climatic parameters for future climate Change in a major agricultural state in India. Climate 9 (7), 111.
Johnson, T.A., Singh, S., Misra, S., Kalpana, S., 2011. Effect of elevated temperature and low rasiation on growth and yield of basmati rice (Oryza sativa L.). Indian J. Plant Physiol. 16 (2), 147.
Joshi, R., Wani, S.H., Singh, B., Bohra, A., Dar, Z.A., Lone, A.A., Singla-Pareek, S.L., 2016. Transcription factors and plants response to drought stress: current understanding and future directions. Front. Plant Sci. 7, 1029.
Kar, S., Das, N., 2015. Climate change, agricultural production, and poverty in India. In: Poverty Reduction Policies and Practices in Developing Asia, 55.
Kashyap, D., Agarwal, T., 2021. Temporal trends of climatic variables and water footprint of rice and wheat production in Punjab, India from 1986 to 2017. J. Water Clim. Change 12 (4), 1203–1219.
Kaul, S., Ram, G., 2008. An assessment of impact of climate change on rice production in India. Agric. Situation India 3, 413–415.
Kaushal, N., Awasthi, R., Gupta, K., Gaur, P., Siddique, K.H., Nayyar, H., 2013. Heat-stress-induced reproductive failures in chickpea (Cicer arietinum) are associated with impaired sucrose metabolism in leaves and anthers. Funct. Plant Biol. 40 (12), 1334–1349.
Kaushika, G.S., Arora, H., KS, H. P., 2019. Analysis of climate change effects on crop water availability for paddy, wheat and berseem. Agric. Water Manag. 225, 105734.
Kingra, P.K., Ramanjit, K., Satinder, K., 2019. Climate change impacts on rice (Oryza sativa) productivity and strategies for its sustainable management. Indian J. Agric. Sci. 89 (2), 171–180.
Kondabolu, S., 2014. A Case Study of Changing Cropping Diversity and Agricultural Risk in the Doulthabad Mandal of Telangana State in India.
Koundinya, A.V.V., Kumar, P.P., Ashadevi, R.K., Hegde, V., Kumar, P.A., 2018. Adaptation and mitigation of climate change in vegetable cultivation: a review. J. Water Clim. Change 9 (1), 17–36.
Kumar, Ajay Sharma, Pritee, Impact of Climate Variation on Agricultural Productivity and Food Security in Rural India (June 23, 2022). Available at SSRN: https://ssrn.com/abstract=4144089 or https://doi.org/10.2139/ssrn.4144089.
Kumar, R., 2012. Effect of climate change and climate variable conditions on litchi (Litchi chinensis Sonn.) productivity and quality. In: IV International Symposium on Lychee, Longan and Other Sapindaceae Fruits, 1029, pp. 145–154.
Kumar, S., Raju, B.M.K., Ramarao, C.A., Ramilan, T., 2015. Sensitivity of livestock production to climatic variability under indian drylands and future perspective. Curr. Agric. Res. J. 3 (02), 142–149.
Kumar, S., Das, A., Kasala, K., Ravula, P., 2022. Micronutrient-sensitive food value chains: a systematic review of intervention strategies and impact pathways to nutritional outcomes. CABI Reviews 2022.

Kumar, V., Chopra, A.K., 2009. Impact of climate change on biodiversity of India with special reference to Himalayan region-an overview. J. Appl. Nat. Sci. 1 (1), 117–122.
Kumar, V., Cheng, S.Y.C., Singh, A.K., 2016. Impact of flood on rural population and strategies for mitigation: a case study of Darbhanga district, Bihar state, India. Contemp. Rural Soc. Work J. 8 (1), 5.
Kumari, V.V., Roy, A., Vijayan, R., Banerjee, P., Verma, V.C., Nalia, A., Hossain, A., 2021. Drought and heat stress in cool-season food legumes in sub-tropical regions: consequences, adaptation, and mitigation strategies. Plants 10 (6), 1038.
Lakshminarayanan, S., 2011. Role of government in public health: current scenario in India and future scope. J. Fam. Community Med. 18 (1), 26.
Lamichaney, A., Tewari, K., Basu, P.S., Katiyar, P.K., Singh, N.P., 2021. Effect of elevated carbon-dioxide on plant growth, physiology, yield and seed quality of chickpea (Cicer arietinum L.) in indo-Gangetic plains. Physiol. Mol. Biol. Plants 27, 251–263.
Lobell, D.B., Sibley, A., Ivan Ortiz-Monasterio, J., 2012. Extreme heat effects on wheat senescence in India. Nat. Clim. Chang. 2 (3), 186–189.
Madhukar, A., Dashora, K., Kumar, V., 2021. Investigating historical climatic impacts on wheat yield in India using a statistical modeling approach. Model. Earth Syst. Environ. 7, 1019–1027.
Magan, N., Medina, A., Aldred, D., 2011. Possible climate-change effects on mycotoxin contamination of food crops pre-and postharvest. Plant Pathol. 60 (1), 150–163.
Mahapatra, B., Walia, M., Rao, C.A.R., Raju, B.M.K., Saggurti, N., 2021. Vulnerability of agriculture to climate change increases the risk of child malnutrition: evidence from a large-scale observational study in India. PLoS One 16 (6), e0253637.
Makwana, M., Patnaik, U., 2021. Vulnerability of marine fisheries to sea surface temperature and cyclonic events: evidences across coastal India. Reg. Stud. Mar. Sci. 48, 102002.
Malhi, G.S., Kaur, M., Kaushik, P., 2021. Impact of climate change on agriculture and its mitigation strategies: a review. Sustainability 13 (3), 1318.
Malik, P.K., Bhatta, R., Takahashi, J., Kohn, R., Prasad, C.S., 2015. Livestock Production and Climate Change, vol. 6. CABI.
Mandal, R., Singha, P., 2020. Impact of climate Change on average yields and their variability of the principal crops in Assam. Indian J. Agric. Econ. 305.
Marai, I.F., Haeeb, A.A.M., 2010. Buffaloes'reproductive and productive traits as affected by heat stress. Tropical Subtropical Agroecosyst. 12 (2), 193–217.
Martin, G.D., Vijay, J.G., Laluraj, C.M., Madhu, N.V., Joseph, T., Nair, M., Balachandran, K.K., 2008. Fresh water influence on nutrient stoichiometry in a tropical estuary, southwest coast of India.
Masters, G., Baker, P., Flood, J., 2010. Climate change and agricultural commodities. CABI Work Pap 2, 1–38.
Mathur, N., Kashyap, S.P., 2000. Agriculture in Gujarat: problems and prospects. Econ. Polit. Wkly. 3137–3146.
Mbow, C., C. Rosenzweig, L.G. Barioni, T.G. Benton, M. Herrero, M. Krishnapillai, E. Liwenga, P. Pradhan, M.G. Rivera-Ferre, T. Sapkota, F.N. Tubiello, Y. Xu, 2019: Food Security. 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 [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, In press.
Mertens, A., Balakrishnan, K., Ramaswamy, P., Rajkumar, P., Ramaprabha, P., Durairaj, N., Arnold, B.F., 2019. Associations between high temperature, heavy rainfall, and diarrhea among young children in rural Tamil Nadu, India: a prospective cohort study. Environ. Health Perspect. 127 (04), 047004.
Mishra, S., Singh, R., Kumar, R., Kalia, A., Panigrahy, S.R., 2017. Impact of climate change on pigeon pea. Econ. Aff. 62 (3), 455–457.
Mohanty, B., Mohanty, S., Sahoo, J., Sharma, A., 2010. Climate change: impacts on fisheries and aquaculture. Clim. Change Variability 119, 978–53.
Mohapatra, D., Kumar, S., Kotwaliwale, N., Singh, K.K., 2017. Critical factors responsible for fungi growth in stored food grains and non-chemical approaches for their control. Ind. Crop. Prod. 108, 162–182.
Mohapatra, S., Mohapatra, S., Han, H., Ariza-Montes, A., López-Martín, MdC, 2022. Climate change and vulnerability of agribusiness: assessment of climate change impact on agricultural productivity. Front. Psychol. 13, 955622. https://doi.org/10.3389/fpsyg.2022.955622.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., PRISMA Group T, 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann. Intern. Med. 151 (4), 264–269.
Mondal, B., Doloi, G., Islam, S.T., Bera, M.M., 2021. Damage Estimation Using Shock Zones: A Case Study of Amphan Tropical Cyclone.
Morner, N.A. (Ed.), 2011. The Tsunami Threat: Research and Technology. BoD–Books on Demand.
Mukherjee, A., Wang, S.Y.S., Promchote, P., 2019a. Examination of the climate factors that reduced wheat yield in Northwest India during the 2000s. Water 11 (2), 343.
Mukherjee, R., Deb, R., Devy, S.M., 2019b. Diversity matters: effects of density compensation in pollination service during rainfall shift. Ecol. Evol. 9 (17), 9701–9711.
Muralidhar, M., Kumaran, M., Jayanthi, M., Muniyandi, B., Ponniah, A.G., Nagothu, U.S., Eknath, A., 2012. Case Study on the Impacts of Climate Change on Shrimp Farming and Developing Adaptation Measures for Small-Scale Shrimp Farmers in Krishna District, Andhra Pradesh, India. Network of Aquaculture Centers in Asia-Pacific, p. 126 (The report is also available online).
Myers, S.S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A.D., Bloom, A.J., Usui, Y., 2014. Increasing CO2 threatens human nutrition. Nature 510 (7503), 139–142.
Nagarajan, S., Jagadish, S.V.K., Prasad, A.H., Thomar, A.K., Anand, A., Pal, M., Agarwal, P.K., 2010. Local climate affects growth, yield and grain quality of aromatic and non-aromatic rice in northwestern India. Agric. Ecosyst. Environ. 138 (3–4), 274–281.
Naik, P.S., Singh, M., Ranjan, J.K., 2017. Impact of climate change on vegetable production and adaptation measures. Abiotic Stress Manage. Resilient Agric. 413–428.
Nandi, G., Neogy, S., Roy, A.K., Datta, D., 2020. Immediate disturbances induced by tropical cyclone Fani on the coastal forest landscape of eastern India: a geospatial analysis. Remote Sens. Appl.: Soc. Environ. 20, 100407.
Narolia, R.S., Meena, D.S., Meena, H.P., Singh, Pratap, Nagar, B.L., 2018. Productivity, profitability and sustainability of soybean (Glycine max)-wheat (Triticum aestivum) cropping system as influenced by improved water management technology in south eastern Rajasthan. Soybean Res. 16 (1–2), 25–33.
Nath, I., 2022. Climate Change, the Food Problem, and the Challenge of Adaptation through Sectoral Reallocation.
Nath, V., Kumar, G., Pandey, S.D., Pandey, S., 2019. Impact of climate change on tropical fruit production systems and its mitigation strategies. Clim. Change Agric. India: Impact Adaptation 129–146.
Nayak, G.D., Behura, N.C., Sardar, K.K., Mishra, P.K., 2015. Effect of climatic variables on production and reproduction traits of colored broiler breeder poultry. Vet. World 8 (4), 472.
Nidumolu, U.B., Hayman, P.T., Hochman, Z., Horan, H., Reddy, D.R., Sreenivas, G., Kadiyala, D.M., 2015. Assessing climate risks in rainfed farming using farmer experience, crop calendars and climate analysis. J. Agric. Sci. 153 (8), 1380–1393.
Niranjana, Murthy, Anand, S.R., Prithviraj, S.K., 2020. Underutilized potential crops for food and nutritional security under changing climate. Mysore J. Agric. Sci. 54 (1), 1–14.
Noushadali, M., 2021. Climate change impact on nutritional status of preschoolers: a cross sectional study. Indian J. Econ. Develop. 9 (1), 1–5.
Pal, Madan, Talawar, S., Deshmukh, P.S., Vishwanathan, C., Khetarpal, S., Kumar, Pramod, Luthria, Devanand, 2008. Growth and yield of chickpea under elevated carbon dioxide concentration. Indian J. Plant Physiol. 13 (4), 367–374.
Panda, A., Sahu, N., Behera, S., Sayama, T., Sahu, L., Avtar, R., Yamada, M., 2019. Impact of climate variability on crop yield in Kalahandi, Bolangir, and Koraput districts of Odisha, India. Climate 7 (11), 126.
Panikkar, P., Sarkar, U.K., Das, B.K., 2022. Exploring climate change trends in major river basins and its impact on the riverine ecology, fish catch and fisheries of the peninsular region of India: issues and a brief overview. J. Water Clim. Change 13 (7), 2690–2699.
Parajuli, R., Thoma, G., Matlock, M.D., 2019. Environmental sustainability of fruit and vegetable production supply chains in the face of climate change: a review. Sci. Total Environ. 650, 2863–2879.
Paria, B., Mishra, P., Behera, B., 2022. Climate change and transition in cropping patterns: district level evidence from West Bengal, India. Environ. Challenges 7, 100499.
Parida, Y., 2017. Effect of flood on rural agricultural wages in Indian states: An empirical analysis. In: Abstracts, 13th Annual Conference on Economic Growth and Development, pp. 18–20.
Pasala, R., Ramesh, K., Praduman, Y., 2018. Recent Advances in Adaptation and Management Strategies for Sustainable Oilseeds Production under Climate Change Scenario.
Patel, N.R., Parida, B.R., Venus, V., Saha, S.K., Dadhwal, V.K., 2012. Analysis of agricultural drought using vegetation temperature condition index (VTCI) from Terra/MODIS satellite data. Environ. Monit. Assess. 184, 7153–7163.
Pattanayak, A., Kumar, K.K., 2014. Weather sensitivity of rice yield: evidence from India. Clim. Change Econ. 5 (04), 1450011.
Paudel, B., Wang, Z., Zhang, Y., Rai, M.K., Paul, P.K., 2021. Climate change and its impacts on farmer's livelihood in different physiographic regions of the trans-boundary koshi river basin, central himalayas. Int. J. Environ. Res. Public Health 18 (13), 7142.
Pooja, G., Pratibha, B., Richa, S., 2019. Effect of heat stress on pulse production. Agric. Update 14 (1), 80–84.
Praveen, B., Sharma, P., 2019. A review of literature on climate change and its impacts on agriculture productivity. J. Public Aff. 19 (4), e1960.
Praveen, B., Sharma, P., 2020. Climate change and its impacts on Indian agriculture: an econometric analysis. J. Public Aff. 20 (1), e1972.
Priyadarshi, S., Ojha, S.N., Sharma, A., 2019. An assessment of vulnerability of fishers livelihood to climate Change in coastal Odisha, India. Curr. World Environ. 14 (1), 60.
Priyanka, B., Patil, R.K., Dwarakanath, S., 2016. A review on detection methods used for foodborne pathogens. Indian J. Med. Res. 144 (3), 327.
Punya, P., Kripa, V., Padua, S., Mohamed, K.S., Nameer, P.O., 2021. Impact of environmental changes on the fishery of motorized and non-motorized sub-sectors of the upwelling zone of Kerala, southeastern Arabian Sea. Estuar. Coast. Shelf Sci. 250, 107144.
Rahman, A., Barman, S., 2019. Perception on Flood impact and source of employment of farmers in Flood affected areas of Assam. Int. J. Curr. Microbiol. App. Sci. 8 (7), 645–651.
Ramachandran, N., 2014. Persisting undernutrition in India. Causes, consequences and possible solutions.
Ramakrishna, G., Gaddam, S.R., Daisy, I., 2014. Impact of floods on food security and livelihoods of IDP tribal households: the case of Khammam region of India. Int. J. Develop. Econ. Sustain. 2 (1), 11–24.
Ramírez, F., Kallarackal, J., 2018. Tree Pollination under Global Climate Change. Springer, Switzerland.

Rana, R.S., Bhagat, R.M., Kalia, V., Lal, H., Sen, V., 2013. Indigenous Perceptions of Climate Change Vis-a-Vis Mountain Agricultural Activities in Himachal Pradesh, India.
Rani, A., Devi, P., Jha, U.C., Sharma, K.D., Siddique, K.H.M., Nayyar, H., 2020. Developing climate-resilient chickpea involving physiological and molecular approaches with a focus on temperature and drought stresses. Front. Plant Sci. 10, 1759.
Rao, C.R., Raju, B.M.K., Josily, S., Rao, A.V.M.S., Kumar, R.N., Rao, M.S., Singh, V.K., 2022. Impact of climate change on productivity of food crops: a sub-national level assessment for India. Environ. Res. Commun. 4 (9), 095001.
Rao, C.S., Gopinath, K.A., Prasad, J.V.N.S., Singh, A.K., 2016. Climate resilient villages for sustainable food security in tropical India: concept, process, technologies, institutions, and impacts. Adv. Agron. 140, 101–214.
Rasool, S., Hamdani, S.A., Ayman, N., Fayaz, A., Shubeena, S., Thahaby, N., Akand, A.H., 2021. The impact of natural disasters on livestock sector: a review. J. ISSN 2766, 2276.
Ray, K., Arora, K., Srivastav, A.K., 2019. Weather Extremes and Agriculture. International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences.
Reddy, B.N., Raghavender, C.R., 2007. Outbreaks of aflatoxicoses in India. Afr. J. Food Agric. Nutr. Dev. 7 (5).
Reddy, P.P., Reddy, P.P., 2015. Impacts of climate change on agriculture. Climate resilient agriculture for ensuring food security 43–90.
Rehman, S., Azhoni, A., Chabbi, P.H., 2022. Livelihood vulnerability assessment and climate change perception analysis in Arunachal Pradesh, India. GeoJournal 1–21.
Revadekar, J.V., Preethi, B., 2012. Statistical analysis of the relationship between summer monsoon precipitation extremes and foodgrain yield over India. Int. J. Climatol. 32 (3), 419–429.
Ritchie, H., Reay, D.S., Higgins, P., 2018. Quantifying, projecting, and addressing India's hidden hunger. Front. Sustain. Food Syst. 2, 11.
Rodriguez-Llanes, J.M., Ranjan-Dash, S., Degomme, O., Mukhopadhyay, A., Guha-Sapir, D., 2011. Child malnutrition and recurrent flooding in rural eastern India: a community-based survey. BMJ Open 1 (2), e000109.
Ruby, P., Ahilan, B., 2018. An overview of climate change impact in fisheries and aquaculture. Climate Change 4 (13), 87–94.
Rupa, T.R., Rejani, R., Bhat, M.G., 2013. Impact of climate change on cashew and adaptation strat[1]egies. In: Climate-Resilient Horticulture: Adaptation and Mitigation Strategies. Springer India India, New Delhi, pp. 189–198.
Sabar, B., Midya, D.K., 2022. Intersecting knowledge with landscape: indigenous agriculture, sustainable food production and response to climate Change–a case study of Chuktia Bhunjia tribe of Odisha, India. J. Asian Afr. Stud. 59(1), 123-141.
Saha, S., Chakraborty, D., Sehgal, V.K., Pal, M., 2015. Potential impact of rising atmospheric CO2 on quality of grains in chickpea (Cicer arietinum L.). Food Chem. 187, 431–436.
Sahoo, A., Nayak, G.D., Das, B.C., Sardar, K.K., 2022. Path Coefficient Analysis of Haemato-Biochemical Traits to Explore the Heat Stress in Native Khadia Chicken Population of Northern Odisha, India.
Sahoo, A.K., Das, B.K., Lianthuamluaia, L., Raman, R.K., Meena, D.K., Roshith, C.M., Sadhukhan, D., 2021. Dynamics of river flows towards sustaining floodplain wetland fisheries under climate change: a case study. Aquat. Ecosyst. Health Manag. 24 (3), 72–82.
Salagrama, Venkatesh, 2013. Climate change and livelihoods: perspectives from small-scale fishing communities in India. Food Chain 3 (1–2), 32–47.
Sam, A.S., Abbas, A., Padmaja, S.S., Sathyan, A.R., Vijayan, D., Kächele, H., Mueller, K., 2021. Flood vulnerability and food security in eastern India: a threat to the achievement of the sustainable development goals. Int. J. Disaster Risk Red. 66, 102589.
Samuel, J., Rao, C.A.R., Raju, B.M.K., Reddy, A.A., Reddy, A.G.K., Kumar, R.N., Prasad, J.V.N.S., 2021. Assessing the impact of climate resilient Technologies in Minimizing Drought Impacts on farm incomes in drylands. Sustainability 14 (1), 382.
Saravanakumar, V., 2015. Impact of Climate Change on Yield of Major Food Crops in Tamil Nadu, India, vol. 91. South Asian Network for Development and Environmental Economics, Kathmandu, Nepal.
Saravanakumar, V., Lohano, H.D., Balasubramanian, R., 2022. A district-level analysis for measuring the effects of climate change on production of rice: evidence from southern India. Theor. Appl. Climatol. 150 (3–4), 941–953.
Sarkar, S., Gil, J.D.B., Keeley, J., Jansen, K., 2021a. The Use of Pesticides in Developing Countries and their Impact on Health and the Right to Food. European Union.
Sarkar, T., Roy, A., Choudhary, S.M., Sarkar, S.K., 2021b. Impact of climate Change and adaptation strategies for fruit crops. In: India: Climate Change Impacts, Mitigation and Adaptation in Developing Countries. Springer International Publishing, Cham, pp. 79–98.
Sarkar, U.K., Borah, B.C., 2018. Flood plain wetland fisheries of India: with special reference to impact of climate change. Wetl. Ecol. Manag. 26, 1–15.
Sarkar, U.K., Bakshi, S., Lianthuamluaia, L., Mishal, P., Das Ghosh, B., Saha, S., Karnatak, G., 2020. Understanding enviro-climatological impact on fish biodiversity of the tropical floodplain wetlands for their sustainable management. Sustain. Water Resour. Manage. 6, 1–12.
Saud, B.J., Bhattacharjya, B.K., Verma, V.K., Kumar, D., Debnath, D., Das, M., Sharma, A. P., 2012. Effect of climate Change on aquatic life with special Refferencence to north-east region of India. Environ. Ecol. 30 (4A), 1534–1537.
Savary, S., Willocquet, L., 2020. Modeling the impact of crop diseases on global food security. Annu. Rev. Phytopathol. 58, 313–341.
Saxena, R., Khan, M.A., Choudhary, B.B., Kanwal, V., 2020. The trajectory of livestock performance in India: a review. Indian J Dairy Sci 72 (6), 569–679.
Sejian, V., Bagath, M., Krishnan, G., Rashamol, V.P., Pragna, P., Devaraj, C., Bhatta, R., 2019. Genes for resilience to heat stress in small ruminants: a review. Small Rumin. Res. 173, 42–53.
Senapati, A.K., 2022. Weather effects and their long-term impact on agricultural yields in Odisha, East India: agricultural policy implications using NARDL approach. J. Public Aff. 22 (3), e2498.
Sengar, R.S., Sengar, K. (Eds.), 2014. Climate Change Effect on Crop Productivity, 1st. CRC Press. https://doi.org/10.1201/b17684.
Senguttuvel, P., Jaldhani, V., Raju, N.S., Balakrishnan, D., Beulah, P., Bhadana, V.P., Voleti, S.R., 2022. Breeding rice for heat tolerance and climate change scenario; possibilities and way forward. A review. Arch. Agron. Soil Sci. 68 (1), 115–132.
Sharma, A., Kumar, B.S., Dubey, P.P., Kashyap, N., 2022. Delay in puberty is dependent on heat shock protein B1 expression in native cross layers of Punjab under heat stress. Reprod. Domest. Anim. 57 (3), 284–291.
Sharma, Bunty, Singh, Vivek K., Sheoran, R.K., Thakral, N.K., Naruka, Anu, 2018. Heat Stress in Plants. Ann. Biol. 34 (1), 70–78.
Sharma, H.C., 2014. Climate change effects on insects: implications for crop protection and food security. J. Crop Improv. 28 (2), 229–259.
Sharma, U., Bairwa, L., Misra, P., 2011. Proceedings of Workshop. National Conference on Forest Diversity: Earth's Living Treasure.
Sheikh, A.A., Bhagat, R., Islam, S.T., Dar, R.R., Sheikh, S.A., Wani, J.M., Dogra, P., 2017. Effect of climate change on reproduction and milk production performance of livestock: a review. J. Pharmacognosy Phytochem. 6 (6), 2062–2064.
Shekhar, M., Singh, N., Bisht, S., Singh, V., Kumar, A., 2018. Effects of climate change on occurrence of aflatoxin and its impacts on maize in India. Int. J. Curr. Microbiol. App. Sci. 7 (6), 109–116.
Shetty, P.K., 2004. Socio-ecological implications of pesticide use in India. Econ. Polit. Wkly. 5261–5267.
Shiferaw, B., Reddy, V.R., Wani, S.P., 2008. Watershed externalities, shifting cropping patterns and groundwater depletion in Indian semi-arid villages: the effect of alternative water pricing policies. Ecol. Econ. 67 (2), 327–340.
Climate change and variability. In: Simard, S. (Ed.), 2010. IntechOpen. https://doi.org/10.5772/1743.
Shinde, A.K., Sejian, V., 2013. Sheep husbandry under changing climate scenario in India: an overview. Indian J. Anim. Sci. 83 (10), 998–1008.
Shukla, K.K., Nongthombom, R., Amit, S., Arifa, K., Kaushik, B., 2014. Climate change: in the context of socio-economic development of Arunachal Pradesh (India)-a review. Trends Biosci. 7 (10), 827–835.
Shyam, S.S., Kripa, V., Zacharia, P.U., Mohan, A., Ambrose, T.V., 2014. Vulnerability assessment of coastal fisher households in Kerala: a climate change perspective. Indian J. Fisheries 61 (4), 99–104.
Singh, A., Phadke, V.S., Patwardhan, A., 2011. Impact of drought and flood on Indian food grain production. Challenges Opportunities Agrometeorol. 421–433.
Singh, A.K., Kumar, S., Jyoti, B., 2022. Influence of climate change on agricultural sustainability in India: a state-wise panel data analysis. Asian J. Agric. 6 (1).
Singh, H., Kaur, P., Bal, S.K., Choudhury, B.U., 2021a. Effect of elevated temperature on green gram [Vigna radiata (I). Wilczek] performance under temperature gradient tunnel (TGT) environment in Punjab. J. Agrometeorol. 23 (1), 3–13.
Singh, I.J., 2013. Impact of climate Change on the apple economy of Himachal Pradesh: A case study of Kotgarh Village. In: Ecology and Tourism (EcoTour-2013), 21–23 NOVEMBER. Lviv Polytechnic National University, Lviv, Ukraine, pp. 20–25.
Singh, M., Lathwal, S.S., Kotresh, P.C., Choudhary, S., Barman, D., Keshri, A., Kumar, R., 2021b. Health status of Hariana cattle (Bos indicus) in different seasons in its breeding tract of Haryana, India. Biol. Rhythm. Res. 52 (6), 910–921.
Singh, N., Sharma, D.P., Chand, H., 2016. Impact of climate change on apple production in India: a review. Curr. World Environ. 11 (1), 251.
Singh, N.P., Singh, S., Anand, B., Ranjith, P.C., 2019. Assessing the impact of climate change on crop yields in Gangetic Plains region, India. J. Agrometeorol. 21 (4), 452–461.
Singh, S.V., Somagond, Y.M., Deshpande, A., 2021c. Nutritional management of dairy animals for sustained production under heat stress scenario. Indian J. Ani. Sci. 91, 337–349.
Sinha, S.K., Swaminathan, M.S., 1991. Deforestation, climate change and sustainable nutrition security: a case study of India. Clim. Chang. 19 (1–2), 201–209.
Sirohi, S., Michaelowa, A., 2007. Sufferer and cause: Indian livestock and climate change. Clim. Chang. 85 (3–4), 285–298.
Solankey, S.S., Prakash, S., Pawan, S., Randhir, K., 2019, March. Vulnerability of vegetable crops to climate change. In: National Seminar on "recent advances in agriculture for sustainable rural development (RAASRD-2019)". VKSCoA, Dumraon (BAU, Sabour), Bihar, pp. 64–70.
Somanathan, E., Somanathan, R., 2009. Climate change: challenges facing India's poor. Econ. Polit. Wkly. 51–58.
Sonawane, G.G., Singh, F., Tripathi, B.N., Dixit, S.K., Kumar, J., Khan, A., 2012. Investigation of an Outbreak in Lambs Associated with *Escherichia coli* O95 Septicaemia.
Sonkar, G., Mall, R.K., Banerjee, T., Singh, N., Kumar, T.L., Chand, R., 2019. Vulnerability of Indian wheat against rising temperature and aerosols. Environ. Pollut. 254, 112946.
Sreekanth, P.D., Venkattakumar, R., Kumar, K.V., Jayanthi, P.K., 2013. Impact of Climate on Oilseed Production in Andhra Pradesh: A Case Study to Understand Regional Level Influences.
Srivastava, S., Mehta, L., 2018. Addressing Climate Change Uncertainty in Dryland Kachchh, India.
Suresh, S.P., Dinesh, T.M., 2015. Sustainable agriculture and livelihood of farmers under drought situation in Hyderabad-Karnataka region-a socio-economic perspective. Karnataka J. Agric. Sci. 28 (5), 861–863.

Swaminathan, M.S., Kesavan, P.C., 2012. Agricultural research in an era of climate change. Agric. Res. 1, 3–11.
Swaminathan, M.S., Rengalakshmi, R., 2016. Impact of extreme weather events in Indian agriculture: enhancing the coping capacity of farm families. Mausam 67 (1), 1–4.
Swaminathan, S., Edward, B.S., Kurpad, A.V., 2013. Micronutrient deficiency and cognitive and physical performance in Indian children. Eur. J. Clin. Nutr. 67 (5), 467–474.
Tesfaye, K., Aggarwal, P.K., Mequanint, F., Shirsath, P.B., Stirling, C.M., Khatri-Chhetri, A., Rahut, D.B., 2017. Climate variability and change in Bihar, India: challenges and opportunities for sustainable crop production. Sustainability 9 (11), 1998.
Thorat, B.N., Thombre, B.M., Badgujar, S.L., Dadge, A.V., Bhutkar, S.S., 2016. Influence of season on peak milk yield in Deoni breed of cattle in Marathwada region of Maharastra state, India. Indian J. Animal Res. 50 (4), 606–609.
Tirlapur, L.N., Desai, N.M., 2017. Impact of climate variability on crop yield in different districts of Gulburga division. Int. Res. J. Agric. Econ. Statist. 8 (1), 176–182.
Tripathi, A., Tripathi, D.K., Chauhan, D.K., Kumar, N., Singh, G.S., 2016. Paradigms of climate change impacts on some major food sources of the world: a review on current knowledge and future prospects. Agric. Ecosyst. Environ. 216, 356–373.
Udmale, P., Ichikawa, Y., Manandhar, S., Ishidaira, H., Kiem, A.S., 2014. Farmers' perception of drought impacts, local adaptation and administrative mitigation measures in Maharashtra state, India. Int. J. Disaster Risk Red. 10, 250–269.
United Nations, 2025. https://www.un.org/en/climatechange/what-is-climate-change accessed on 2nd March 2025.
Vaidya, P., Randhawa, S., Sharma, P., Sharma, Y.P., Satyarthi, K., Randhawa, S.S., 2019. Climatic variability during different phenophases and its impact on temperate fruit crops. J. Agrometeorol. 21 (3), 366–371.
Vani, S., Joseph, Mini, 2020. A study on the nutritional impact of Kerala floods 2018 on the Kuttanad residents of Alleppey district -a KSCSTE funded project.International. J. Home Sci. 2020 6 (1), 12–15.
Vass, K.K., Das, M.K., Srivastava, P.K., Dey, S., 2009. Assessing the impact of climate change on inland fisheries in river ganga and its plains in India. Aquat. Ecosyst. Health Manag. 12 (2), 138–151.
Vedeld, T., Salunke, S.G., Aandahl, G., Lanjekar, P., 2014. Governing Extreme Climate Events in Maharashtra, India. Final Report on WP3. 2: Extreme Risks, Vulnerabilities and Community-based Adaptation in India (EVA): A Pilot Study. CIENS-TERI.
Vedwan, N., Rhoades, R.E., 2001. Climate change in the Western Himalayas of India: a study of local perception and response. Clim. Res. 19 (2), 109–117.
Veerakumaran, G., Santhi, S.L., 2019. Impact Assessment of Kerala Flood 2018 on Agriculture of Farmers in Edathua Panchayat. Kuttanad Taluk of Alappuzha District.
Vishnu, C.R., Sridharan, R., 2016. A case study on impact of Chennai floods: supply chain perspective. Ind. Eng. J. 9 (8), 12–16.
Viswanathan, B., Kumar, K.K., 2015. Weather, agriculture and rural migration: evidence from state and district level migration in India. Environ. Dev. Econ. 20 (4), 469–492.
Vivekanandan, E., 2013. Climate change: challenging the sustainability of marine fisheries and ecosystems. J. Aquatic Biol. Fisheries 1 (1 & 2), 54–67.
Wenndt, A., Sudini, H.K., Pingali, P., Nelson, R., 2020. Exploring aflatoxin contamination and household-level exposure risk in diverse Indian food systems. PLoS One 15 (10), e0240565.
Yadav, M.K., Singh, R.S., Singh, K.K., Mall, R.K., Patel, C.B., Yadav, S.K., Singh, M.K., 2015. Assessment of climate change impact on productivity of different cereal crops in Varanasi, India. J. Agrometeorol. 17 (2), 179–184.
Yadav, M.K., Singh, R.S., Singh, K.K., Mall, R.K., Patel, C., Yadav, S.K., Singh, M.K., 2016. Assessment of climate change impact on pulse, oilseed and vegetable crops at Varanasi, India. J. Agrometeorol. 18 (1), 13–21.
Yadav, M.P., Singh, R.K., Malik, Y.S., 2020. Emerging and transboundary animal viral diseases: perspectives and preparedness. Emerg. Transboundary Animal Viruses 1–25.
Yadav, R., Kalia, S., Rangan, P., Pradheep, K., Rao, G.P., Kaur, V., Siddique, K.H., 2022. Current research trends and prospects for yield and quality improvement in sesame, an important oilseed crop. Front. Plant Sci. 13, 978.
Younis, F.E., Khidr, R.E., 2020. Mitigation and adaptation strategies for livestock to cope with climate change challenges: review and perspective. Animal Sci. Reporter 13 (4), 1–11.