ICRISAT AND WFP: India Working Paper

Effects of Climate Change on Food Security and Nutrition in India

A SYSTEMATIC REVIEW

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1. Introduction

Climate change[1] 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 & 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 impacts 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 has 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 & 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 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 & Kumar, 2015; Priyadarshini 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. Therefore, there is a need to undertake a systematic review of the existing literature to understand the effects of climate change on food security and nutrition in India and to identify evidence gaps. **This systematic review aims to synthesize the available evidence on the effect of climate change on food security and nutrition in India**. The review examines the literature on the effects of climate change and variability on food production and availability, food access, and the nutritional status of the Indian population.

The findings of this systematic review contribute to 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 evidence gaps in the existing literature and highlights the need for further research in limited areas. Ultimately, this systematic review aims to help policymakers and other

1 The climate is the average weather pattern for a particular place over several decades. Climate change refers to long-term changes in weather, including changes in temperature, wind pattern, and rainfall, especially the increase in temperature of the earth's atmosphere, which is caused by an increase in the concentration of greenhouse gasses (GHGs), particularly carbon dioxide (Kingra et al., 2019, https://www.un.org/en/climatechange/what-is-climate-change).

stakeholders make informed decisions to improve food security and nutrition and adapt to climate change.

The subsequent section presents the study's methodology and details the study's characteristics.

In the next section, we delve into the literature review on the effect of climate change on food security and nutrition, then explore potential areas for future research. The last section concludes with the presentation of our findings.

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2. Methods

PROTOCOL

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

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 pin 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).

All the themes, subthemes, and relevant queries are presented in Table 1 in Appendix.

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.

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 2 in the Appendix.

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3. Study Characteristics

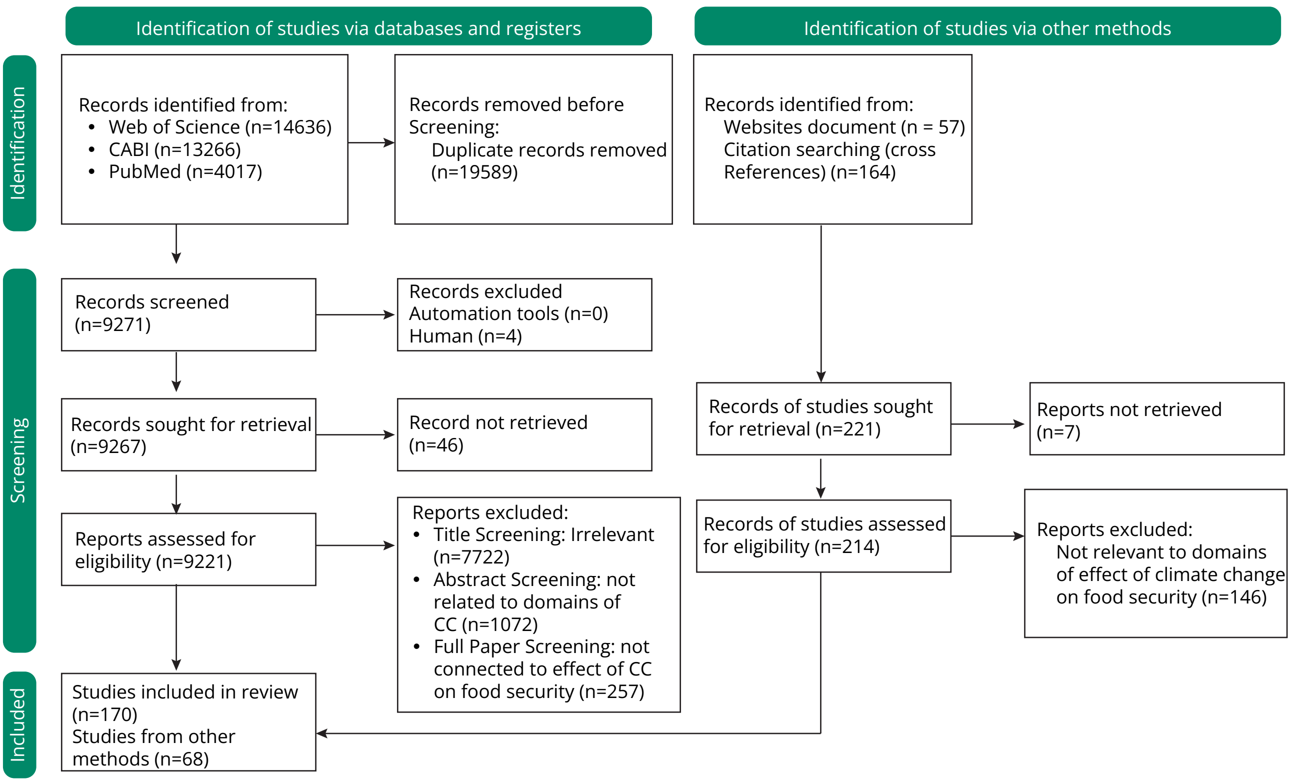
From the search of three bibliographic databases and different web searches, we retrieved 9271 articles. After using the search criteria (described in the previous section), finally, we pin down 238 research studies. The detailed PRISMA flow diagram (Figure 1) shows step-by-step maps of the number of records identified, included, and excluded and the reasons for exclusions for undertaking the present review.

DIMENSION-WISE DISTRIBUTION

The allocation of research studies on India, as illustrated in Figure 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 Figure 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

***Figure 1**: PRISMA flow diagram of the systematic review on effect of climate change on food security and nutrition in Indian context*

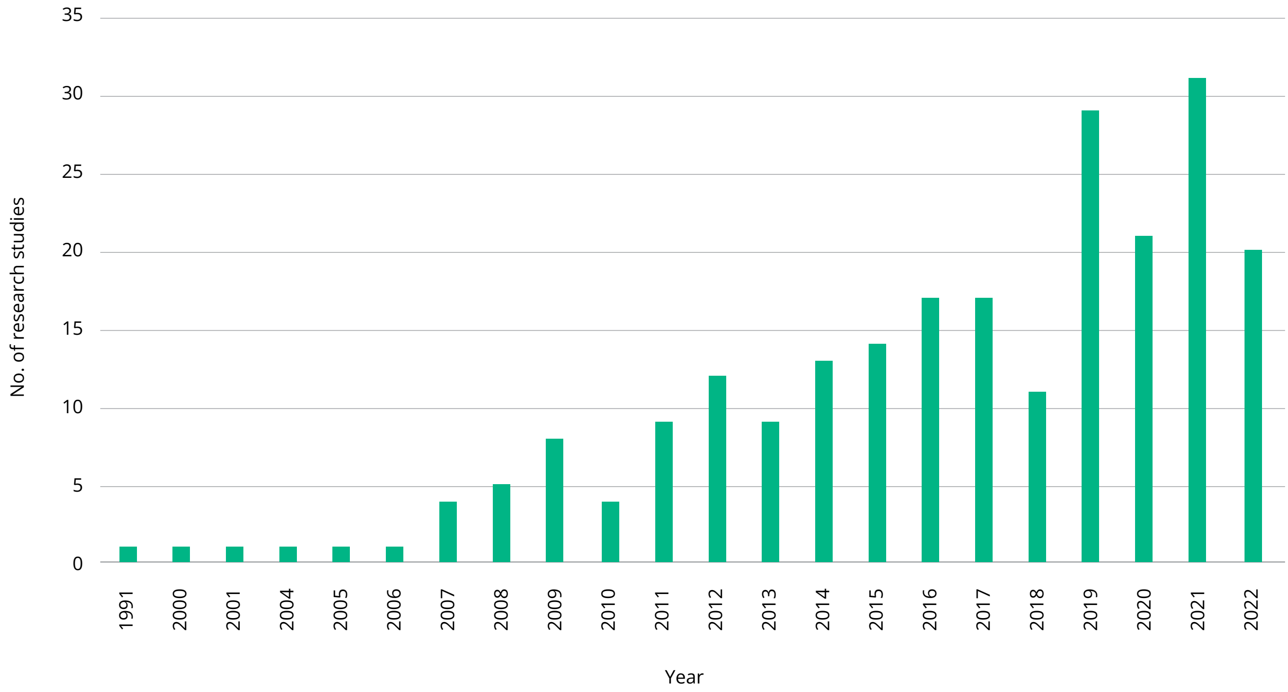


ruminants (n=8), and poultry birds (n=6), are relatively fewer compared to crop production. The number of research studies dedicated to understanding the impact of climate change on aquaculture production (n=21) is also relatively low, followed by fruit and vegetable production (n=18). This detailed comparison demonstrates that while 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 source 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 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,

***Figure 2**: Distribution of research studies based on food security dimensions*

Figure 3: Year wise distribution of research 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.

YEAR-WISE DISTRIBUTION

Over the past one 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 Figure 3 for a detailed listing of publications by year, considering research studies until October 2022 for the present review.

STATE-WISE DISTRIBUTION

Figure 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.

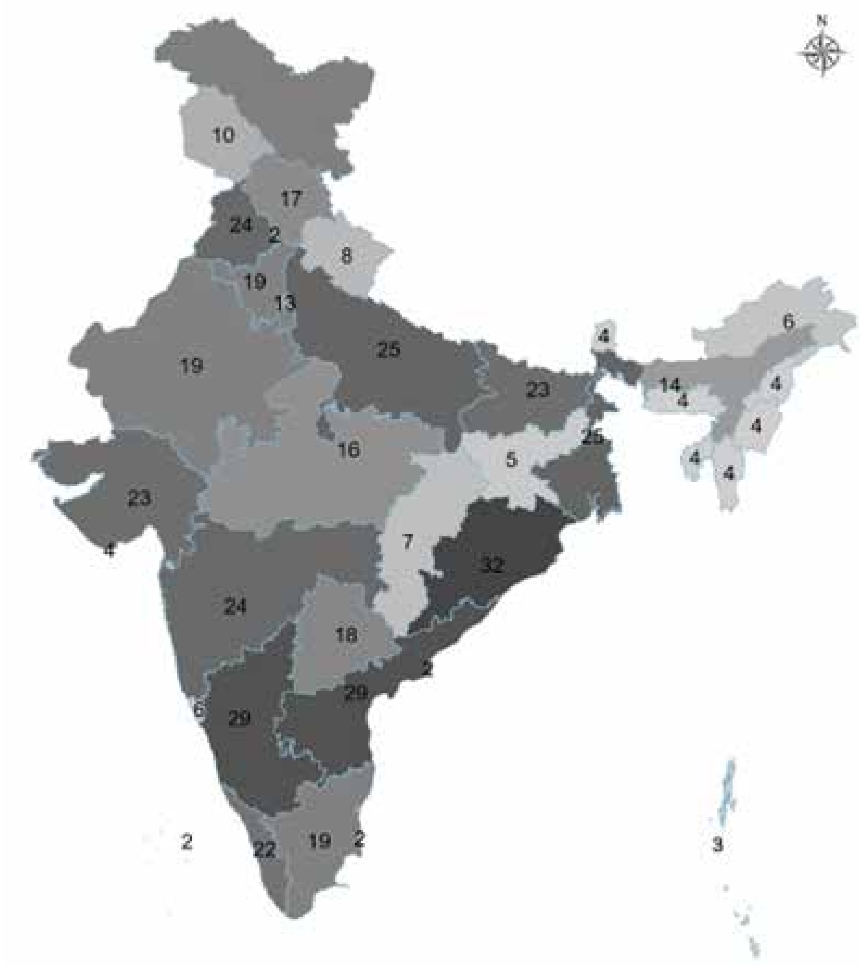
The number of studies undertaken varied significantly across regions. Odisha (n=32) has the highest number of research studies indicating a strong focus on understanding the effect of climate change on food security in that state. Karnataka(n=30) and Andhra Pradesh(n=28) also have number of studies. 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 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 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.

Figure 4: Distribution of research studies across India



CLIMATE ATTRIBUTES WISE DISTRIBUTION

In this review, we have reported four significant environmental variables and their combinations (Temperature, Rainfall, Extreme events, and Others) to understand the effect of climate change on India's food security and nutrition. The research studies reviewed included these environmental attributes were temperature (n=140), rainfall (n=82), extreme events (n=64), and others (n=14). As combination of these attributes, the review includes 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); temperature, rainfall and extreme event (n=15).

4. Effect of Climate Change on Food Security and Nutrition

FRAMEWORK

The effect of climate change on the four pillars of food security, namely food availability, food access, food utilization, and food stability, is significant (FAO, 2002, 2006). To objectively understand the effect of the phenomena, there is a need to examine climate change effects on several subparts within each of these pillars. In our present study, we have adopted a structured approach from IPCC (Mbow et al., 2019) to comprehend the effect of climate change on food security and nutrition in India.

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. 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.

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 & 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 & 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 & Singha, 2020; Singh et al., 2019). Research has shown that rising temperatures reduce yields ranging between 10-40 % for rice, 2-10% for wheat, 2-12% percent for maize, and 10-12 % for sorghum crop (Murthy et al., 2020; Nidumolu et al., 2015; Yadav et al., 2015; Praveen & Sharma, 2020; Savary & Willocquet, 2020; Senguttuvel et al., 2022; Kingra et al., 2019; Aryal et al., 2019; Sinha & Swaminathan, 1991; Mukherjee et al., 2019; Madhukar et al., 2021; Sonkar et al., 2019; Kaul & Ram, 2008; Guntukula & Goyari, 2020) delay crop maturity and increase pest and disease, causing economic losses for farmers (Praveen & 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 & 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 et al., 2020; Panda et al., 2019; Senapati, 2022; Guntukula, 2020; Ghosh-Jerath et al., 2021; Tripathi et al., 2016; Saravana Kumar et al., 2022). Sorghum yields in India are expected to decline due to changes in rainfall patterns (Saravana Kumar, 2015; Tirlapur & 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 & Preethi, 2012). Studies have also shown a significant negative effect of precipitation change on maize yields in Telangana (Guntukula & 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., 2021). 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., 2021). 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 most 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

Fruits and vegetable production is highly vulnerable to climate change at their reproductive stages and also due to increased disease incidence because of climate variability. The rising temperature and reduced precipitation are bound to affect the horticultural crops of the region (Sarkar et al., 2021; Paudel et al., 2021). The effects can be at any crop growth and development stage, thus influencing the quality and yield (Bhardwaj & 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 un-conducive 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 meters 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 & 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 et al., 2012; Bhardwaj, 2019). Higher temperatures during the growing season lead 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 are not limited to crops. It affects food security via its direct or indirect effect on other components of the agricultural production systems, especially livestock production, which is closely linked with crop production. The relationships between livestock populations and the environment are complex, and there are many ways in which climate change may affect livestock and livestock systems.

We discuss the effects of climate change on livestock in three different parts: 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; Sheik et al., 2017).

High temperatures lead to heat stress, which causes reduced feed intake, lower productivity, and increased mortality (Sirohi & Michaelowa, 2007; Chauhan & Ghosh, 2014). Moreover, heat stress reduces milk production of cattle and buffalo by up to 50% (Sheik et al., 2017; Thorat et al., 2016; Dhaliwal et al., 2021). Similarly, thermal stress decrease milk yield and quality in buffaloes (Marai & Habeeb, 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 local breed cows like Deoni and Sahiwal cows in Maharashtra (Das and Singh, 2016).

Changes in rainfall patterns and the availability of water and forage also affect large ruminants in India (Saxena et al., 2020; Singh et al., 2021). As temperature increases, the growth and quality of vegetation be affected, leading to a decrease in the availability of high-quality feed for animals (Balhara et al., 2017; Malik et al., 2015). This lead to lower productivity and increased susceptibility to diseases. Changes in forage availability also affect the nutritional status of animals, leading to increased susceptibility to heat stress and other environmental challenges (Giridhar & Samireddypalle, 2015).

Climate change also increases the incidence of diseases in large ruminants. For example, tick-borne diseases such as babesiosis and anaplasmosis increase as temperatures rise, based on a study in Haryana (Ganguly et al., 2017). Similarly, fungal infections such as dermatophytosis and ringworm increase with increased humidity and rainfall (Gupta & Singh, 2021). These diseases lead to reduced productivity and increased 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 N et al., 2012; Gupta & 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 & Khidr, 2020). Heat stress significantly reduces the reproductive performance of small ruminants, leading to reduced conception rates and increased embryonic mortality (Gupta & Mondal, 2021; Shinde & 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 & 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 & 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, 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 (Rao, 2016; 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 (Rao, 2016).

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 (Priyadarshini et al., 2019). Climate change threatens fisheries resources and fish production, as observed in Jammu and Kashmir, Himachal Pradesh, Punjab, and Kerala (Sarkar & 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 lead 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 & 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 & 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 provides 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 lead to reduced crop yields, reduced livestock productivity, and declining fish stocks (Swaminathan & 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 toward 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 Aggarwal, 2016; Viswanathan & 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, neglect of their children's health and education as seen in Karnataka (Bhor & 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 evidences 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 & 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 & 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 & 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 & 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 & 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 includes the nutrient composition of food, its preparation, and its overall state of health (Mbow et al., 2019). Food safety and quality directly affect food utilization (Magam et al., 2011). Therefore, we discuss the effect of climate change on food utilization in 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 (Lakshmiarayann et al., 2011; FAO, 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 et al., 2009; 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., 2021; 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 & Raghavender, 2007; Wenndt et al., 2020; Shekar 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 the 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 & 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 & Rhoades, 2001; Mukherjee et al., 2019). 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 & 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., 2021). The increase in temperature has also led to new animal diseases (Yadav et al., 2020; GoI 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 (CO_2), methane (CH_4), nitrous oxide (N_2O), and tropospheric ozone (referred to as O_3), have seen a substantial increase. Of these GHGs, CO_2 and O_3 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 CO_2 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 CO_2 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 CO_2 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 & Rengalakshmi, 2016; Ray et al., 2019; Srivastava & 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 & Sridharan, 2016; Kumar et al., 2016; Samuel et al., 2021; Suresh & 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., 2016; Kumar et al., 2016;). Various studies conducted in India have documented the adverse effects of extreme weather events on food security and nutrition (Vishnu & 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 & Santhi, 2019; Vani & Joseph, 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 & Santhi, 2019; Chowdhury et al., 2022; Rahman & 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 & 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; Venkatesh, 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

Distribution of food aid to vulnerable communities often depends on complex logistics, transportation, and storage systems. These systems are sensitive to severe weather events, such as road closures due to flooding or storage damage due to high winds. This has resulted in delays in the distribution of food aid and even loss of perishable food items.

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

The effect of climate change on food aid distribution in Odisha, Tamil Nadu, West Bengal, and Andhra Pradesh, particularly in the context of child nutrition, was also studied (Rodriguez-Llanes et al., 2011; Bartlett, 2008). The 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, the number of studies conducted on this aspect is limited.

5. Potential for Future Research

The effect of climate change on food and nutrition security is a complex, multifaceted issue with far-reaching consequences for human health, well-being, and sustainable development. In India, a country with a large and diverse population, climate change effects on food security and nutrition may be particularly acute and multidimensional. Given the growing severity of the phenomena and a recognition of the importance of tackling climate change to ensure food security in India, there are still significant research gaps that need to be addressed to better understand the its impact, challenges and opportunities in the context of food security and nutrition. As this systematic review highlights that a large number of studies in India have generated very useful information on the effect of climate change on different dimensions of food security and nutrition however there are still evidence gaps. Moreover, a majority of these studies are based on controlled experiments or macro-level analysis using country or state or district level indicators. Therefore, micro-level studies at farm household and village level would be needed and are critical for designing effective adaptation policies for sustainable food security and nutrition in the country under climate change scenario. Based on this literature review, following are some of important areas needed for more evidence generation:

- **The need for research on the effect of climate change on crop productivity, traditional crops, and their nutritional value, particularly in marginal and remote areas and marginalized populations such as tribal populations, smallholder farmers, and women of India**.

  Traditional crops, such as millets, sorghum, and pulses, are often adapted to local environmental conditions and are critical to ensuring food and nutritional security. However, climate change may affect these crops' growth and nutritional value, particularly in marginal and remote areas where farming practices may be more traditional and less resilient. More research is needed to understand how climate change may affect these traditional crops and how farmers will adapt to ensure food security and nutritional.

  Extreme weather events, such as droughts, floods, and heat waves, severely affect crop productivity, particularly for smallholder farmers and women with limited access to resources and technology. More research is needed to understand how extreme weather affects different crops, regions, and populations and how farmers can adapt to mitigate these effects.

  Tribal areas of India are often more vulnerable to the effects of climate change on food production and utilization, as they may have limited access to resources, infrastructure and technology. More research is needed to understand how climate change may affect food security and nutrition in tribal areas of India and how community-led local adaptation strategies can be developed to enhance resilience and ensure food and nutritional security.

  Vulnerable populations such as women and children may be particularly susceptible to the effects of climate change affecting their nutrition. More research is needed to understand how climate change may affect nutrition outcomes and how interventions can be designed to ensure food security and nutrition for the vulnerable populations.

- **Development of evidence base on the long-term effects of climate change on soil fertility, nutrient availability, and the sustainability of agricultural systems in India.**

  Climate change may affect soil fertility, health and nutrient availability in various ways, including precipitation patterns, temperature, and carbon dioxide levels in different agro-ecological zones. Further emphasis on the evidence base for better decision-making is needed to understand how these changes may affect the sustainability of agricultural systems and how farmers will adapt to ensure long-term food security and nutrition.

- **Exploration of the effect of climate change on indigenous food systems, traditional knowledge,**

cultural heritage, agricultural biodiversity, and its potential effect on food security and nutrition.

Indigenous food systems and traditional knowledge are important for maintaining biodiversity and cultural heritage and may provide valuable insights into adaptation strategies in the face of climate change. However, climate change may affect the availability and diversity of these food systems and may also contribute to the loss of traditional knowledge. More research is needed to understand how climate change may affect indigenous food systems and traditional knowledge in India and how this may affect food security, nutrition, and cultural heritage.

Climate change may affect agricultural biodiversity in various ways, including changes in temperature, rainfall, and pest populations. More research is needed to understand how these changes may affect the diversity of crops and livestock in India and how this may affect food and nutritional security.

- **Rigorous and robust research on the effects of climate change on food distribution systems, its access and the potential for food price volatility and food insecurity.**

  Climate change may affect food distribution systems and access in various ways, including changes in transportation infrastructure, market demand, and supply chain disruptions. Sufficient evidence is not available on this dimension including its inter-sectoral impacts. More research is needed to understand how climate change may affect food distribution systems and access in India and how this may affect food price volatility and food insecurity as well as associated other economic and welfare activities.

- **Extensive studies are needed to better understand the effect of climate change on fisheries and aquaculture, particularly on small-scale fishers and coastal communities.**

  Climate change may affect fish stocks and aquatic ecosystems, including temperature, acidity, and sea level changes. More research is needed to understand how these changes may affect fisheries and aquaculture in India and how this may affect food security and nutrition, particularly for small-scale fishers and coastal communities and also the potential context-specific adaptation strategies.

- **Advance potential research inquiries on the effect of climate change on food waste and loss and the potential for reducing food waste through climate-smart agriculture.**

  Food waste and loss are major issues in India, and climate change may exacerbate it by affecting food production, distribution and access. More research is needed to understand how climate change may affect food waste and loss in India and how climate-smart agriculture can help to reduce food waste and loss while ensuring food security and nutrition.

- **Emphasis on the effect of climate change on food and nutritional security in urban areas and the potential for urban agriculture and food systems to contribute to adaptation and resilience.**

  Urban areas are particularly vulnerable to the effects of climate change in terms of food security and nutrition, as they are often dependent on food systems that are highly vulnerable to supply chain disruptions and extreme weather events. More research is needed to understand how climate change may affect food security and nutrition in urban areas of India and how urban agriculture and food systems can be developed to enhance their adaptation and resilience.

- **Additional focused research on the social, economic, and political dimensions of climate change and food security and nutrition in India, including issues of gender, equity, and governance.**

  Climate change and food security and nutrition are complex issues influenced by various social, economic, and political factors. More research is needed to understand the social, economic, and political dimensions of these issues in India, including gender, equity, and governance, and how these factors may affect the vulnerability and resilience of different populations and regions.

The potential research gaps discussed above highlight the urgent need for a more comprehensive and integrated approach to address the effects of climate change on food security and nutrition in India. By filling these research gaps, we can better understand the challenges and opportunities to develop more effective and equitable policies and strategies to increase the resilience and sustainability of food systems in the face of a changing climate. Ultimately, food security and nutrition will require a coordinated, collaborative effort involving policymakers, scientists, civil society organizations, and local communities to adapt to climate change to ensure that the benefits and costs of adaptation and mitigation strategies are fairly distributed so that no one is left behind in the transition towards a more sustainable and resilient food system.

6. Conclusions

The effect of climate change on food and nutrition security in India is a complex issue with varying degrees. This systematic review of the existing literature on the subject revealed that climate change significantly affects food security in India in multiple ways. Along with temperature increases and irregular rainfall, extreme weather events such as floods, droughts, heat waves, etc., adversely affect crop, livestock, poultry and aquaculture production and causes food shortages, income loss and rising food prices, disproportionately affecting low-income populations. Climate change also indirectly affects food security and nutrition through its effect on livelihoods and incomes. Furthermore, climate change is exacerbating existing inequalities, resulting in the displacement of marginalized communities and increasing food insecurity and malnutrition.

This study though present good information on the effect of climate change on different dimensions of food security and nutrition. There are evidence gaps in knowledge in certain aspects as indicated in the previous section however the evidence gaps on micro-level analysis of climate change effect at farm household and village level is of particular concern. The micro-level understanding is critical for designing effective and equitable adaptation policies.

Overall, the review finds that more research is needed to understand the complex, multifaceted effects of climate change on food security and nutrition in India. In addition, food security in India requires more targeted interventions and policies that can address the context-specific challenges posed by climate change.

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