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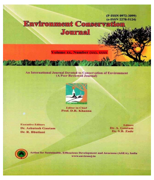

Effect of climate change on agriculture and its management

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ABSTRACT

Globally, agriculture is being greatly impacted by climate change, with agricultural output in regions such as India being reduced by rising heat stress, drought, and floods. Typhoons and floods are two examples of extreme weather events that harm agricultural infrastructure and force farmers to relocate. The changing growing season, precipitation pattern, and insect pressure are already negatively affecting agricultural productivity and are expected to worsen. The quantity and quality of food supplies are under threat due to the rising worldwide demand for wholesome and sustainable food production as well as the difficulties associated with climate change. Climate change is a topic that is addressed through international accords and programmes, including the UNFCCC, the Paris Agreement, and the Renewable Energy Transition. To lessen the consequences of climate change, programmes are being developed that emphasize renewable energy, reforestation, and climatic resilience. The nutritional and physical quality of food are also impacted by climate change; these changes include changes in carbohydrate, protein, lipid, mineral, and physical characteristics. Government initiatives, climate-smart food systems, financial incentives for dietary changes, and cross-disciplinary research are examples of mitigation measures. Crops that can withstand heat, water, and climatic anomalies are developed through plant breeding. While there may be some benefits associated with climate change, such as the expansion of particular crops, the impact on food production as a whole is questionable and calls for further study as well as increased public awareness among society.

Introduction

Climate change is influencing agriculture in several places worldwide. Climate change is causing greater heat stress, drought, and floods in India, all of which are reducing crop production. A severe drought in India in 2014 resulted in crop losses of up to 50% in certain places. Climate change is creating more extreme weather events, such as typhoons and floods, in the Philippines. These occurrences have caused damage to agricultural infrastructure and crops, as well as the displacement of farmers. Climate change is already causing noticeable shifts in growing seasons, precipitation patterns, and the prevalence of pests and diseases in the United States. These alterations are currently exerting a detrimental impact on agricultural production and are anticipated to be exacerbated in the future. As we look ahead, our global food system will encounter unprecedented challenges, as outlined by (Battisti and Naylor 2009). On the one hand, the demand for sustainable and nutritious food production will persistently increase, propelled by the continuous growth of the world's population until mid-century and the rapid economic development fostering the expansion of the global middle class. On the other

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hand, climate change will lead to higher temperatures, modifications in rainfall patterns, and an increase in the frequency of natural disasters. If left unaddressed, these factors are projected to curtail the growth in global food production by an estimated 2 percent per decade for the remainder of this century, as noted by (Trenberth in 2011). According to the United Nations Framework Convention on Climate Change, climate change is defined as "a change that is attributed directly or indirectly to human activity, which alters the composition of the global atmosphere and is in addition to natural climate variability observed over comparable time periods" (Bodansky, 1993). By 2050, the population of the globe is anticipated to reach 10 billion. Global food consumption may increase by 59 to 98% as a result of an additional 3.4 billion mouths to feed and rising middle-class demand for meat and dairy in developing nations (Ali and Pappa, 2011). To fulfill these rising demands, agriculture must accelerate output and increase yields globally. However, scientists caution that the impacts of climate change, such as higher temperatures, extreme weather events, droughts, increasing levels of carbon dioxide, and rising sea levels, pose serious threats to the quantity and quality of our food supplies (Singh and Singh, 2012). Addressing these challenges is crucial for safeguarding food security in the face of a changing climate. In 1824, Jacques Fournier proposed a hypothesis suggesting that climate change could be linked to greenhouse gases. This idea was later substantiated by Gilbert Plass in 1940. To monitor and address climate change, the World Meteorological Organization (WMO) established the Intergovernmental Panel on Climate Change (IPCC) in 1988, as documented by Heymann *et al.* (2010). Presently, several ongoing global climate change initiatives and programs are in place. These include the Climate Change Framework Convention of the United Nations (UNFCCC), the Paris Agreement, efforts toward Renewable Energy Transition, Reforestation and Forest Conservation, and endeavors to enhance climate resilience and adaptation. These initiatives represent global efforts to address the challenges posed by climate change and work toward a sustainable and climate-resilient future. The UN Framework Convention on Climate Change (UNFCCC) is an international treaty designed to address climate change. It hosts annual Conference of the Parties (COP) meetings where global climate action is discussed and negotiated. The most recent COP event before my knowledge cutoff was COP26, held in Glasgow, Scotland, in 2021. During this conference, there was a strong focus on intensifying efforts to combat climate change and foster international cooperation. A substantial worldwide agreement for reducing climate change was reached in 2015 and is called the Paris Agreement. The aim is to maintain the temperature at 1.5 degrees Celsius, and the objective is to keep global warming far below 2 degrees Celsius above preindustrial levels. To carry out their obligations under this agreement, countries worldwide have been putting different programmes and initiatives into practice. A crucial step in our collaborative efforts to mitigate the effects of climate change and protect the planet's future is the Paris Agreement. In line with climate change mitigation efforts, numerous governments and regions have actively advocated for the transition to renewable energy sources as part of the Renewable Energy Transition initiative. These efforts encompass the establishment of large-scale solar and wind farms, the promotion of energy-efficient practices, and the enactment of legislation to incentivize the adoption of renewable energy in sectors such as transportation and industry. These proactive measures reflect a commitment to reducing greenhouse gas emissions and fostering a more sustainable and environmentally friendly energy landscape. In recent years, projects centered around reforestation, afforestation, and forest conservation have garnered significant attention. These initiatives are aimed at restoring and safeguarding forests, which play a critical role in capturing carbon dioxide and combating climate change. Activities within these efforts encompass tree-planting campaigns, efforts to reduce deforestation rates, and the adoption of sustainable forest management practices. Recognizing the necessity of bolstering resilience against climate change impacts, several projects are dedicated to enhancing adaptive capacity in vulnerable communities and sectors. These projects entail the development of early warning systems, the implementation of climate-smart agricultural practices, the construction of climate-resilient infrastructure, and the promotion of communitybased adaptation strategies. These proactive measures underscore the importance of building a more resilient and sustainable future in the face of a changing climate. Climate change has two primary causes: natural and anthropogenic. Natural causes include continental drift, volcanic activity, shifts in the Earth's tectonic plates, ocean currents, and variations in solar radiation. On the other hand, anthropogenic causes are human-induced and involve the emission of greenhouse gases such as carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, ozone, and water vapor. Other human activities, such as deforestation and urbanization, also contribute to climate change (Puhe and Ulrich, 2012). Certain climatic variables, such as droughts, hailstorms, and frosts, play crucial roles in causing adverse conditions and can have significant impacts on food production. These variables include temperature, rainfall, light, and relative humidity. Temperature, in particular, is vital for the growth of crops, as it influences the initiation of floral buds, full bloom, fruiting, color development, and maturity (Trenberth *et al*., 2002). These factors underscore the delicate balance required for optimal agricultural productivity and the vulnerability of crops to changes in climate variables. In tropical areas, flower drop is common when temperatures are high. On the other hand, temperate crops require a specific chilling temperature for a certain duration to initiate flowering, leading to increased fruit set. However, climate change disrupts these critical temperature requirements, ultimately decreasing the quantity and quality of food produced (Adekunle and Oyerinde 2012). Climate change manifests in various extreme weather events, such as droughts, floods, heatwaves, alterations in rainfall patterns, weakening monsoons, and changes in atmospheric composition (e.g., stubble burning in India). These climatic shifts have been linked to famines in regions such as the Sahel region of Africa, highlighting the devastating impact on food security. Greenhouse gases are the primary culprits behind global warming, with carbon dioxide (CO2) being the most prevalent (82%), followed by methane (CH4) at 10%, nitrous oxide (N2O) at 6%, fluorinated gases at 3%, and water vapor. Nitrous oxide is the third most significant greenhouse gas after carbon dioxide and methane. The sources of N2O emissions include agricultural soil management (74%), stationary combustion (8%), chemical industries (6%), and manure management (5%) (Herndon *et al*., 2018). These greenhouse gas emissions contributed to the warming of the planet, exacerbating climate change and its far-reaching consequences.

Effect of climate change parameters on food production

The following are the primary consequences of climate change on agriculture: temperature, carbon dioxide, ozone, relative humidity, precipitation patterns and soil erosion. Soil erosion, nitrogen depletion, and waterlogging can all be caused by climate change, reducing soil quality and agricultural output.

Effect of temperature

Elevated temperatures have a significant impact on the life cycles of insect pests and diseases, leading to shorter durations of disease, which, in turn, can facilitate their reproduction and proliferation in fields and during storage. The effects of temperature on plants are primarily mediated by changes in plant biochemistry (Chapman *et al*., 2012). This phenomenon is especially prominent in well-watered plants, where the Q10 factor (the rate of increase when the temperature rises by ten degrees) for growth is notably high. Most physiological processes occur normally within a temperature range of 0°C to 40°C (Moretti *et al*., 2010). However, the temperature range for fruit and vegetable crops is significantly smaller. This range can be pushed toward 0°C for temperate species coming from cold climates, such as carrots and lettuce, depending on the species and ecological origin. On the other hand, tropical plants, including a variety of cucurbit and cactus species, may experience cardinal temperatures as high as 40°C (Mauriya *et al*., 2016). The aforementioned ratio is often greater than ten at approximately 15°C, which explains why many plants perform better in temperate settings than in tropical settings. Elevated temperatures lengthen the frost-free season and lower the likelihood that cereals will be harmed by frost; however, temperatures above 30°C can cause cereal flowers to become infertile because pollen viability and germ tube development are compromised (McClintock *et al*., 2008). For every 1°C increase, the growing period of the wheat plants was reduced by 1-3 days. For every 1°C increase in temperature above 15°C during grain filling, grain production will decrease by 3%, and yield losses will be greater than increases in grain protein percentage (Kimball *et al.*, 1995).

Carbon dioxide effect

According to Mattos *et al.* (2014), increased atmospheric CO2 levels have various effects on plant physiology and biochemistry, including changes in net photosynthesis, biomass production, sugar and organic acid content, stomatal conductance, firmness, seed yield, light, water, and nutrient use efficiency. Long-term exposure to greater CO2 levels may increase the likelihood of tuber malformation, increase sugar levels in potatoes, and decrease protein and mineral contents, all of which compromise nutritional and sensory quality. Moreover, the combination of higher carbon dioxide concentrations and temperatures has the potential to enhance biological productivity, which, in turn, could lead to increased crop yields. This complex interplay of factors highlights the importance of understanding the implications of elevated CO_2 levels for plant growth, crop quality, and food production in the context of climate change. These consequences, nevertheless, will be mitigated by the faster pace of development and, consequently, shorter crop growth duration, which are caused by higher temperatures. The availability of carbon dioxide likely limits the growth rate of C-3 crops, such as wheat, barley, and oats, which have experienced increased growth. However, it is doubtful that the development of plants with a C_4 photosynthetic system, such as maize, would change (Ziegler *et al.*, 1989).

Ozone effect

When leaf tissue undergoes this type of stress, it can have consequences on the photosynthetic rate, biomass production, and, ultimately, postharvest quality concerning overall appearance, color, and flavor compounds. Exposure to ozone in the atmosphere results in reduced photosynthesis and accelerated turnover of antioxidant systems. This heightened presence of ozone can have adverse effects on the postharvest quality of fruit and vegetable crops. Elevated ozone concentrations can cause visual injuries and physiological disorders in various plant species, leading to significant alterations in essential quality parameters such as dry matter, reducing sugars, citric acid, malic acid, and other important compounds (Moretti *et al.*, 2010). As a result, these changes in postharvest quality may result in compromised appearance, taste, and overall acceptability for consumers. This finding underscores the importance of addressing and mitigating the impact of ozone exposure on fruit and vegetable crops to ensure optimal quality and marketability.

Relative humidity and precipitation pattern effects

These changes can result in altered growing seasons, higher drought risk, and more intense weather events, all of which affect agricultural output. Warmer temperatures and shifting precipitation patterns can provide ideal circumstances for pests and diseases to thrive, reducing agricultural output even further. Unusual rains can dampen a mature crop before harvesting and trigger mold formation, which might subsequently lower grain quality, force some of the grain to be thrown, and increase the risk of contamination by aflatoxins or other mycotoxins. The active components in some commercial grain protectants may perform less effectively at higher temperatures and humidity levels, which might lead to a crop that degrades more quickly chemically and biologically. The chemical and biological degradation of substances may be accelerated by these climate change events, resulting in a reduction in shelf life. Increased prestorage and storage losses result from harvesting while rainy outside. When crops are harvested and moist, drying becomes challenging, which increases the danger of mycotoxin contamination and might result in rotting or germination (Dhurrin in sorghum). Grain management costs increase as a result of climate change events harming storage facilities, making it more difficult to reprocess dampened grains and causing difficulties with inventory management and forecasting (Chegere, 2018).

Impact of climate change parameters on the nutritional and physical quality of foods

Carbohydrates

Williams *et al.* studied the impacts of climate change on wheat carbohydrates and concluded that increased temperature (2-4°C) had a far greater impact than CO_2 on starch content, grain size, grain number, and gelatinization. In red kidney bean, compared to 28/18°C (day/night) temperatures and

350 ppm CO_2, elevated temperatures (34/24°C) and 700 ppm CO2 cause low synthesis of simple sugars, as glucose 44% decreases, and high production of di- and polysaccharides, such as sucrose, by 33% and raffinose, by 116% (Thomas *et al.*, 2009). Increased raffinose causes digestive problems in nonruminant animals and humans since they do not possess galactosidase enzymes (Sebastian *et al.*, 2000). In barley, elevated temperatures from 24/17°C to 37/17°C during the day/night cause starch incorporation 21 days earlier than in the control, during which the A-type starch granule content (with a particle size of 10 to 50 µm) increases, whereas the B-type granule content (5–10 µm) decreases, thereby decreasing the malt yield. A small increase in mealiness is associated with elevated temperatures in barley because heat-treated endosperm plants exhibit increased susceptibility to enzymatic attack, which is beneficial for the malting process (Yang *et al.*, 2007 and Barnabas *et al.*, 2008). A study related to the effect of elevated carbon dioxide concentrations on the physicochemical characteristics and milling quality of rice was conducted, and the inamylose content and milled rice content decreased by 3.6% and 2%, respectively, whereas the head rice and chalky grain and chalkiness degree increased by 23.5%, 16.9% and 28.3%, respectively.

Proteins

Elevated CO_2 increases photosynthesis in plants and thus leads to high carbohydrate synthesis but low protein levels. Elevated CO_2 decreases the nutritional quality of plants in terms of quality proteins and causes dietary deficiency diseases in animals; moreover, elevated CO2 has adverse effects on baking quality since proteins play a major role in the preparation of baked goods. When the temperature was raised to 1°C, there was a 0.4% increase in protein content, but when 56 kg ha^{-1} nitrogen fertilizer was applied to the same crop, the protein content increased to 1% (Benzian and Lane 1986).

Lipids

The total lipid content in wheat decreases by 21.5% under elevated CO_2 at 700 ppm (Williams *et al.*, 1995). In soybean, along with a 21.5% decrease in lipid content, there is a reduction in linolenic acid content and an increase in oleic acid content under elevated temperatures greater than 32/22°C (day/night) (Thomas *et al.*, 2009).

Minerals

In plants, mineral assimilation is affected by climate change. Elevated CO_2 causes a significant reduction in the mineral content of rice, with 14%, 5%, 17%, and 28% nitrogen, phosphorus, iron and zinc, respectively, but the calcium content increases by 32% (Seneweera and Conroy 1997). In wheat, elevated CO_2 leads to a 3.7–18.3% reduction in total mineral content (Hogy and Fangmeier 2008).

Physical attributes

Under relatively high temperatures during growth and development, the activity of cell wall enzymes such as cellulase and polygalacturonase decreases, leading to delayed ripening in fruits. For instance, mandarins exposed to direct sunlight at 35°C exhibit a firmness approximately 2.5 times greater than that of mandarins on the shaded side at 20°C. Additionally, variable precipitation and moisture stress trends can cause changes in the chemical composition of fruits. The impact of high temperatures is evident in the Aki Queen variety of grapes, which subsequently experience abnormal coloration (Webb *et al.*, 2007). These findings highlight how temperature variations during fruit development can significantly influence fruit physical and chemical properties, underscoring the importance of understanding and managing environmental conditions for optimal fruit quality.

Effect of climate change on microbial contamination of foods

Studies with elevated CO2 levels, typically doubling from 350 ppm to 700 ppm, have revealed that although the photosynthetic rates of C-3 plants increase by more than 25%, those of C-4 plants increase very slightly. In maize, F. *verticillioides,* an endophyte, and F. *graminearum* tend to predominate in warm temperate zones, whereas F. *culmorum* predominates in cooler temperate regions. According to Xu *et al.* (2008), F. *graminearum* produces deoxynivalenol (DON), nivalenol (NIV) or zearalenone (ZER), but F. *culmorum* generates only DON and ZER. F. *culmorum* will be replaced by F. *graminearum*, which will result in a pathogen and possibly a change in Europe and Asia from a DON/ZER contamination pattern to an NIV/ZER contamination pattern. This would not happen in the Americas since the majority of American *F. graminearum* strains are DON producers. The Liseola genus is particularly preferred at temperatures greater than 28°C. Fumonisins and moniliformin are substances that are produced by Liseola. Even though FM has been found in rice and isolates from rice are just as capable of producing FM and MON as isolates from maize are, these substances are currently uncommon in this product (Desjardins *et al*., 1997). F. *verticillioides* causes "bakane" (foolish rice disease, the symptoms of which are caused by mold producing gibberellic acid) and sheath rot in rice.

Climate change mitigation

Government initiatives

In addition to promoting investments in processing and value-adding opportunities and equipment, government and other organizations should also conduct research studies that monitor changes in the dynamics of storage pest populations, illnesses, damage, geographic distribution, host ranges, and farmers' management and coping mechanisms. Early warning systems, emergent response systems, and seasonal and weather forecasting systems should be implemented. Risk management and insurance for climate change should be encouraged. The primary adaptation strategies for postharvest agriculture to climate change include 'good' postharvest management practices, such as reducing the risk of carrying pests from the field to stores through proper sorting, reducing mycotoxin cross contamination by properly redrying insect-damaged or damped grains, protecting dried grains from rain by using covered or roofed drying structures or storing them in airtight containers or efficient packaging materials such as sup.

Smart food systems for the climate

A transition to climate-smart food systems is encouraged through the Inter Academy Partnership. Moreover, reducing GHG emissions from agriculture alone will not be adequate for mitigating the impact of food systems on climate change (De Jaramillo *et al*., 2021).

Encouragements for customers to alter their diets

For the sake of public health, including obesity and nutrition, as well as the environment, there must be incentives for individuals to modify their diets. The causes of demand must be understood by policymakers to alter consumer behavior and promote the acceptance of novel meals and diets. In addition, consumers need assistance from policymakers in understanding and weighing the environmental effects of their food choices. It is important to prioritize reducing food waste since it presents a great opportunity for positive effects on the environment and the climate (Hawkes *et al*., 2013).

Innovative cuisine

Policymakers and other decision makers must make bold attempts to change consumer habits that contribute to greenhouse gas emissions. Reduced meat consumption in some places, such as Europe, or an increase in novel foods and diets, for example, might have positive effects on both health and the environment. Beef-mushroom mixtures, lab-grown beef, algae, and enticing insect-based dishes are a few examples of new foods (Metcalfe *et al*., 2009).

Altering one's diet

Reducing the consumption of wheat, eggs, dairy, poultry, nuts, and seeds while increasing the consumption of legumes, despite having a relatively high blue water footprint, is a significant source of protein and is among the dietary changes. India utilizes more water for agriculture than Western countries do, but its per-person diet-related greenhouse gas emissions are lower (Damerau *et al*., 2019).

Cooperation between society and the natural sciences

It is necessary to translate research into practical innovation, but doing so will require deeper ties across different academic fields, cutting-edge technology, science education, training, and outreach. Social science and policy research on food, nutrition, and agriculture must work much more closely with life sciences and fundamental research.

Plant breeding

Plant breeding offers a promising approach for identifying and developing heat-, water-, and climate-tolerant crops and varieties suitable for various agroecological regions. This effort aims to address the challenges posed by changing environmental conditions. Additionally, the creation of crop simulation models for food crops allows for a better understanding of regional impacts, adaptation strategies, and vulnerability analysis. Interestingly, other plant species shared 68 significant unique regions of similarity (SURFs) with rice, despite having undergone approximately 180 million years of evolution. This unexpected finding highlights the intricate and fascinating connections between plant species, providing valuable insights into their shared evolutionary history. These discoveries could inform future research and efforts in crop improvement and biodiversity conservation. Rice, a wild species that thrived in tropical areas and developed the ability to withstand monsoons and waterlogging, was domesticated from this species. According to Kumary (2011) and Rauf *et al.* (2016), several of the genes involved in this adaptation exist in other plants but have not evolved to turn on when the roots are flooded.

Advantages and disadvantages of climate change

The benefits of this treatment include increased C-3 crop (wheat, barley, and oats) growth. As the temperature increases, the number of frost-free days increases, and grain damage from frost decreases. As temperatures rise, crops in the field dry out more quickly, and insect infestations decline. The drawbacks of this treatment include pollen viability, germ tube development, and floral infertility, which are decreased by exposure to elevated temperatures greater than 30°C. The grain milling loss increases with increasing temperature. Farmer labor hours are affected by heat stress. According to Chauhan *et al.* (2014), moist circumstances make conventional drying challenging.

Future strategies

To generate greater awareness among policy makers and the general public, research communication must expand beyond the farm gate. This is necessary if the objective of maintaining increasing production and quality is to be accomplished. To predict biological processes and their interconnections and to experimentally validate such models, trends must be identified. Research on the physiology, phenology, growth, yield, and quality of food crops under stress from high temperatures, CO2, and excess and insufficient water. To experimentally validate biological processes and their interconnections, trend analysis is crucial. Beyond the farm gate, research must be communicated to increase policy makers' knowledge.

Conclusion

The future of food production is uncertain due to the challenges posed by rising atmospheric CO2, global warming, and changes in precipitation patterns. The potential impacts of pests and diseases in a changing climate are still not fully understood and could have significant implications for food security in the coming years. Although studies conducted thus far can provide insights into the possible consequences of climate change, the specific patterns of its effects remain uncertain. As we continue to grapple with the complexities of climate change, further research and understanding are needed to develop effective strategies for ensuring future food security.

Conflict of interest

The authors declare that they have no conflicts of interest.

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