The Impact of Climate Change on Plant and Its Effect on Global Warming and Food Security: A Critical Review

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Abstract

In order to fulfil the needs of a growing global population, agricultural output must double globally by 2050, but climate change makes this task much more difficult. Drought, heat, and environmental stress are major factors that affect agricultural growth and are important drivers of food security. Furthermore, the genetic diversity of crop species and the environment are being further degraded by forced relocation of cultivated areas due to global warming, which has a knock-on impact on food security and threatens the existence of many species, including those that provide us with food. This study examines the impact of climate change on agricultural and natural ecosystem sustainability, as well as the function of genomes, proteomics, metabolomics, phenomics, and ionomics in the realm of omics technologies. The discussion is on the use of resource-saving technologies, such precision agriculture and novel fertilizing techniques, in plant breeding to enhance tolerance and flexibility. Additionally, these technologies are seen as means of mitigating the effects of climate change and global warming. However, a variety of pressures may affect plants. This work establishes the foundation for the proposal of a fresh research paradigm known as a holistic approach, which extended beyond the narrow idea of crop yield to encompass sustainability, the socioeconomic effects of production, marketing, and the management of agroecosystems.

Keywords: Global warming, Omics, Global change, Holistic approach, Food security

Introduction

A strong correlation exists between agricultural productivity and climate change. It is already well known that fluctuations in average temperatures and rainfall are only two of the ways that global warming impacts agriculture. The drawbacks of this phenomenon include the predictability of extreme meteorological events (such as heat waves, floods, and droughts), changes in pests and diseases, an increase in ground-level ozone concentrations and atmospheric carbon dioxide, and changes in the nutritional quality of food.

The link between climate change and the sustainability of agricultural and natural ecosystems is examined in this research, along with the impact of genomes, proteomics, metabolomics, phenomics, and ionomics technologies. New fertilizers and additives, together with resource-saving technologies like precision agriculture, may help improve crops so they are more resilient to climate change. To attain sustained food security, however, a more comprehensive understanding of agriculture and food production must be adopted.

This is especially true in light of the fact that heat events will become more frequent and intense in the future, particularly in tropical regions (both geographically and nationally), and that over 15% of the world's land will be exposed to higher levels of heat stress, which will have an impact on human health and food production.

Over the past century, the production of food has relied less on around 2500 distinct plant species and more on the "four queens": rice, wheat, maize, and soybeans (Figure 1), as reported by Smþkal et al. (2018). Two thirds of the energy needed by humans comes from these crops, while only the grain legumes give 33% of the necessary proteins for human diets. Food security and environmental sustainability are impacted by this (Foyer et al., 2016). Climate uncertainty (Foley et al., 2011) combined with a persistent reliance on such a limited number of agricultural commodities (Khoury et al., 2014) may contribute significantly to political vulnerability and economic instability. According to recent reviews reporting on the threshold temperatures for several crop species evaluating the impact of global temperature increases on the production of these commodity crops is therefore a critical step for maintaining global food security.

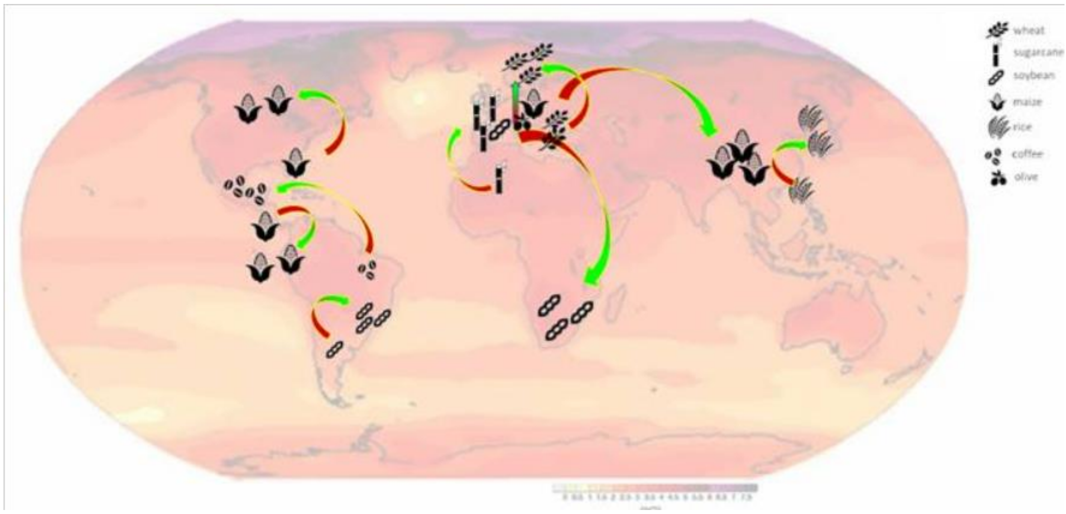

Figure 1:

The map represents the shift in the production of the particular crops in some of the known regions that would be caused by the climate change and global warming projected in the next IPPN study (year 2081-2100).

Many physiological processes in a plant which lead ultimately to the quality and the size of the seed may be implemented by HS. Grain filling largely displaces hexose sugars like fructose and sugar nucleotides like ADP-glucose (Yang et al., 2018); this decline in sugars might be the result of stronger assimilation and utilization rather than an increase in their accumulation. It has been demonstrated that there is considerably less starch accumulation in rice (Yamakawa and Hakata, 2010), maize (Yang, et al., 2018), and wheat (Hurkman, et al., 2003) due to this genetic engineering. The maize storages experienced degradation in quality due to presence of a higher protein content and a lower waxy grain starch quantity (Yang et al., 2018). Moreover, the warming temperatures and increased CO2 also led to foods like carbohydrate and oil to have more nutrients such as more proteins and micronutrients (Chakraborty and Newton, 2011; Li et al., 2018). The free amino acid totality could be found less concentrated inside soybeans after we could find the same for the total protein under HS that in consequence the total oil has increased drastically. Next, HS naturally incurs profits when materials from upstream areas and production activities are running out while the backwater areas are receiving raw materials.

A net increase in crop productivity is unlikely if increased CO2 is combined with high temperatures and/or water scarcity, as emerging evidence has shown. Despite the possibility that the "fertilization effect" of increasing CO2 concentration may benefit crop biomass and increase the possibility of increased food production (Degener, 2015), this is not the case. Thus, the question of water supply is closely related. According to estimates, the total area under irrigation and rainfed cultivation expanded by 159% for soybeans, 35% for maize, 0.3% for wheat, and 13% for rice between 1990 and 2020. While rainfed areas of rice and wheat fell by 7% and 10%, respectively, rainfed areas of maize grew by 24% (as opposed to the 35% growth in the overall area) and 158% in soybeans, with rainfed areas accounting for the majority of the increase in soybean areas.

Furthermore, according to Parthasarathi et al. (2022) there is a reduction of 7.4% in worldwide maize yield, 6.0% in wheat yield, 6.2% in rice yield, 9.0–13.8% in head rice, 8.1–11.0% in total milling profit, and 3.1% in soybean yield for every 1°C increase in the global mean temperature.

Drought and heatwave combined result in production losses of 11.3%, 12.1%, and 12.5% for cereals like wheat, barley, and maize, and 8.4%, 8.4%, 6.2%, and 3.5% for non-cereals like oil crops, 6.2% for olives, 3.5% for vegetables, 4.5% for roots and tubers, and 8.8% for sugar beet, among other things (Brás et al., 2021).

Plant resilience, agroecosystem resilience, and temperature tolerance

The term "global warming" was used in 1975 after observations of a rise in global temperature dating back to the 1970s (Broecker, 1975). In fact, most investigations have issued a warning that HS brought on by rises in global temperature may result in a fall in world yield owing to eco-physiological stress (Sadok and Jagadish, 2020; Zhu et al., 2022).

Indeed, sophisticated modeling-derived forecasts of climate change risks consistently point to a detrimental impact on agricultural productivity as well as a decline in food quality and nutritional qualities (Chakraborty and Newton, 2011). Regional temperature increases may be predicted more accurately by climate models than other changes, such precipitation. According to Zhao et al. (2017), multimethod analysis may increase our confidence in the evaluation of certain elements and outcomes of future climate influences on agricultural yield and provide information regarding the adoption of certain rescue techniques. The likelihood of a catastrophic departure is comparatively understudied and poorly understood, despite thirty years of attempts and considerable success little the United Nations Framework Convention on Climate Change (UNFCCC) to curb greenhouse gas (GHG) emissions. (Kemp et al., 2022).

The production and crop selection specialization, together with the expansion of economic scale, have resulted in a significant rise in productivity within agroecosystems. However, given what the current complex agroecosystems provide—not only for harvest, but also for other significant ecosystem services of enormous social and economic value—the long-term sustainability of these may be compromised by some of the constraints brought on by global warming (Di Falco and Chavas, 2008).

Many studies have primarily discussed how HS affects agricultural output, emphasizing the part that molecular processes play in underlying plant resistance and yield decline (Table 1). The majority, however, did not think that HS and global warming were important synergistic issues affecting food security (Table 1).

Table 1: Recent reviews and articles mostly addressed the impact of heat stress on crop productivity as well as the key elements of defensive mechanisms.

Focus	Author	Type of article
Reducing the effects of climate change on ecosystem sustainability and plant yield.	Pareek et al., 2020	Special Issue
A thorough discussion of the molecular processes behind temperature sensitivity is included, along with an overview of the control of the development and fertilization of the male and female reproductive organs and heat-induced anomalies during blooming.	Lohani et al., 2020	Review
Plant growth regulators (PGRs) are essential for defending against high temperatures (HTS).	Sharma et al., 2020	Research Article

Focus	Author	Type of article
The molecular and genetic underpinnings of agricultural plants' reactions to heat stress and breeding for greater yield and resistance.	Janni et al., 2020	Review
Impacts of global warming and heat stress on grapes.	Venios et al., 2020	Review
Effects on heat on agricultural workers' health.	Lima et al., 2021	Review
The immediate future implications and predictions of climate change, as well as how they will affect agriculture and plant physiology and metabolism, are all discussed. consequences for pest invasion, plant development and production, mitigation techniques, and their financial effect.	Malhi et al., 2021	Review
Effects of a mixture of multifactorial stresses on soil, plant, and microbiological populations.	Zandalinas et al., 2021	Review
Over the last 50 years, crop losses in Europe due to heatwaves and droughts have quadrupled in intensity. An overview of the development of the climate catastrophe and its effects on agricultural productivity is provided by the review.	Brás et al., 2021	Review
Summarizes how heat stress affects a plant's development systems, concentrating on integrated morpho-anatomical, physiological, and molecular responses. Additionally, it offers details on sophisticated heat tolerance systems found in a variety of plant species that use a combination of genetic approaches and other strategies to promote plant growth and development.	Ul Hassan et al., 2021	Review
Wheat's Response to Changing Climates: Effects, Tolerance, Adaptation, and Mitigation of Heat Stress	Yadav et al., 2022	Review
The research emphasizes how crucial crop production modeling under heat stress is to agricultural adaptation, food security, and climate change mitigation.	Zhao et al., 2022	Review
The review summarizes the knowledge on food crops' response and tolerance mechanisms.	Han et al., 2022	Review
The review presents the most recent omics research on crops under abiotic stress, namely heat stress.	Zhou et al., 2022	Review
Heat-responsive molecular regulatory networks regulated by the PHYTOCHROME INTER-ACTING FACTOR 4 (PIF4) and Heat Shock Transcription Factor (HSF)–Heat Shock Protein (HSP) pathways, respectively	Zhou et al., 2022	Review
The review discussed how heat stress affects vegetables and included new findings, highlighting how omics and genome editing	Saeed et al., 2023	Review

The ability of the associated agroecosystems to sustain yield under harsh climatic circumstances, such as high temperatures, may be used to characterize the resilience of cropping systems to global warming and temperature increases. An ecosystem's ability to continue functioning, being unique, and being organized even in the face of a significant disruption is referred to as its resilience (Holling, 1978). This concept is challenging for agroecosystems because of the bias of human intervention; nonetheless, measures of resilience may be considered in a framework that makes use of many phenological markers.

Context-dependent agroecosystem characteristics may be comprehensively described by the term resilience. However, due to abrupt or slow changes in environment, a system that is deemed robust today may not remain such over the course of years or even months (Holling, 2001). Because it requires a constant distribution of energy resources to sustain existence at the expense of growth and reproduction, tolerance to temperature stress has a cost, requiring a trade-off between yield and maintenance.

Agroecosystem management requires an understanding of both social and biological factors. However, the effects of global warming and climate change may cause such abrupt, profound, and unanticipated changes that present agroecosystems may not be able to adjust. The majority of these species run the danger of becoming extinct if global change persists in its intensity and direction, according to a recent meta-analysis of 10,000 animal species that solely took phenological features into account. It's probable that preserving our agroecosystems' greatest degree of variety won't be enough to stop global change and its consequences on food security.

Although temperature increases and global warming are undoubtedly dangerous occurrences, it may be difficult to separate their individual components. Nevertheless, these phenomena are often used as stressor examples. Plants that are resistant to temperature increases and global warming may be able to survive HS without experiencing any appreciable changes in their growth patterns or yield.

Utilizing innovative fertilizers and biostimulants to boost plant resistance

Soil desertification and decrease in the plant production are, as has been mentioned before, the major reason for the climate differences, such as high temperature, droughts, and salt buildup. These are the exceptional conditions, where the biostimulants can be very supportive as plant defenses are induced through various mechanisms, which include molecular changes, physiological, biochemical, and anatomical modifications (Bhupenchandra et al., 2022, Sangiorgio et al., 2020). This is achieved by enhancing plant cellular hypersensitivity, deposition of callose material, and enrichment of the plant's lignin content (Bhupenchandra et al., 2022).

Global CO2 emissions are estimated to be 500 million tons yearly with conventional chemical fertilizers' production accounting for the significant portion of it (FAO, 2020). The livestock sector on the other hand, which is responsible for almost half of the total agricultural greenhouse gas emissions, leads in the production of organic fertilizers (Ramakrishnan et al., 2021;Timsina, 2018). Nanofertilizers (Kah et al., 2018), biofertilizers (Bhardwaj et al., 2014), and novel soil amendments

(Rombel et al., 2022) are being targeted nowadays as sustainable substitutes for fossil fuel fertilizers.

In comparison with inorganic fertilizers, nanofertilizers have some advantages like slow and gradual nutrient release throughout the growth duration and this prevents the surface runoff. Scarcely does the nutrients reach the nearby water bodies and that is a preventive measure against eutrofication (Zulfiqar et al., 2019). However, the price of manufacture of nanofertilizers remains unaffordable for most farmers and their use relies on of farmer acceptance and policies of the government. If the development rate is very slow, then we can expect, in the future, biological (green) production of bio-nanofertilizers to be a viable solution (Zulfiqar et al., 2019).

Biochar has garnered interest among the recently developed soil improvers because: i) it is produced from the pyrolysis or the pyrogasification of removable biomasses which result in small amounts of CO2 being released; ii) it holds CO2 in the soil through the fact it has rather a high porosity and absorbent qualities of both water and nutrients; iii) it provides homes with stable niche in soils where PGPM (plant growth-promoting micro New findings showed that grain biochar "enhanced" with PGPMs on wheat and maize displayed physiological characteristics of plants such as higher plant performance in optimal soil biodiversity, and better crop-soil interactions (Graziano et al., 2022). Recently, a matrix illustrating the pros and cons of utilising biochar specifically elaborated and published was composed (Marmiroli et al., 2022).

These advanced BSTs really a significant nourishment and growth and developmental tool in a context of global warming for plant nutriture and well-being. Microorganisms also stimulate the plant immune system, thus raise the plant's inherent resistance to variable stimuli (both biotic and abiotic), improve water holding capacity of the soil (tagged as "pore water holding capacity") and push the plant to tolerate mild water drought, whence nutrients release more gradually and become more distributive.

Most recent developments in omics for thermal robustness

In recent decades, a multitude of innovative omic technologies have been used to examine the alterations in the genome, transcriptome, proteome, and metabolome that transpire with changes in plant stress conditions. These technologies include genomics, proteomics, metabolomics, phenomics, and ionomics (Wani, 2019). Finding a long-lasting answer to the issues raised requires combining the separate knowledge that omics technologies give on genes, genomes, RNAomes, proteomes, and metabolomes. As reported by Muthamilarasan et al. (2019), the "integromics" research on a stress-responsive behavior of an organism is a process which involves the comparative analysis of the structure and organization of genome and genes looking at their composition and arrangement. It then uses metabolomics As proposed by Pita-Barbosa and colleagues (2019), ionomics is a molecular approach capable of conducting high-throughput profiling of the elemental constituents of biological specimens (ionome) in living things. Ionomics has identified a number of genes that control the ionome and have shown their relationship in determining environmental adaptation via the application of genetics' and high-throughput elemental profiling techniques (Zhang et al., 2021;

Huang & Salt, 2016).

Numerous reviews have focused on the genes that are varicose and which have been proven to be associated with heat stress (Masouleh and Sassine, 2020; Wang et al., 2020; Zhao et al., 2020; Kang et al., 2022). Proteomics has comprehended the role of plant types and developmental stages in stress tolerance mechanisms through encoded proteins in studies (Priya et al., 2019; Katam et al., 2020). (Chaturvedi et al. 2021; Janni et al. 2020). Protein post-translational modifications of the diverse types are responsible for the adaptative reaction to heat shock factor. It was now discovered that the stress-related active proteins (SAAPs) increase the accumulation of the wheat. (Kumar et al., 2019).

Neutral environmental stress which requires reconfiguration of metabolic processes such as function at homeostasis and production of metabolites with signal transduction through the activation of stress survival pathway is now well established (Schwachtje and others, 2019). Furthermore, the conclusion is made by means of the usage of metabolomics untargeting on a number of species, which were citrus (Zandalinas et al., 2017), rice (Sun et al., 2022), soybean (Xu et al., 2016), tomato (Paupière et al., 2017), maize (Qu et The adaptation response under heat stress and the response under combined stressors (e.g. heat and drought) is striking due to the increase in sugars and free amino acids, as well as antioxidants, fatty acids, and organic compounds (Vu et al., 2018). Also, ROS that are produced during HS generally serve as target molecules for lipid, which is an important element that composes the cell and organelle membrane (Narayanan et al., 2016; Narayanan et al., 2018).A fascinating relationship was discovered between the kinds of metabolites involved and the requirement to shield particular cellular processes or cell compartments from the damaging effects of stress, highlighting the use of metabolomics techniques to identify novel genetic material for breeding.

The use of biosensors in controlled environments and the field improves understanding of the mechanisms underlying metabolomics and ionomics, can significantly increase the effectiveness of water management, and can provide breeders with information on the genotypes that are most resilient (Coppedè et al., 2017; Janni et al., 2019).

A comprehensive approach combined with knowledge-based tactics to address global shifts

Soon, rising temperatures and global warming will have a big impact on everything from the economy to daily living. In many parts of the globe, heat waves occur sometimes throughout the summer. However, as a result of climate change, heat waves are becoming more often and powerful, which means that the hazards they pose to the agricultural industry need to be carefully considered (Figure 2). Prolonged exposure to heat has a more negative economic impact on a quantitative indicator of agricultural production. More specifically, the FAO Crop Production Index decreases by about 3% when at least eight days before a very hot day. The heat-wave metric suggests production decreases per wave in other industries up to $31.9 billion and in agriculture between $0.8 and 3.1 billion (Miller et al., 2021). Additionally, according to ensembled mean forecasts, average annual losses per nation by 2091–2100 will be 10.3% of agricultural production without taking mitigation techniques into account and 4.5% with adaptation (Miller et al., 2021).

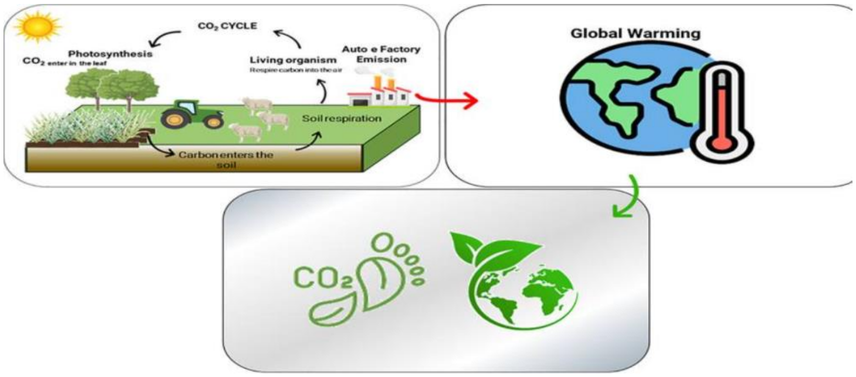

Figure 2 shows the relationship, seen holistically, between soil, CO2 emissions, global warming, and sustainability.

The goal of breeding is to take the lead in reducing the impacts of global warming. During the Green Revolution, it was used as a method to increase yields by crossing popular crops with smaller, harder varieties. These were utilized by farmers in conjunction with stronger herbicides, effective fertilizers, and enhanced irrigation techniques (Rehm, 2018). In order to adapt to environmental changes and enhance sustainability, breeders, farmers, and modelers collaborate, which embodies the holistic approach philosophy required to meet the problem of global warming.

Therefore, a comprehensive and diversified strategy that views crop production as only one component of agroecosystem stress resistance is required to meet the global climate crisis. It is essential to take into account the agroecosystem, the plant, and the cutting-edge technology now accessible while designing more adaptive crops.

As a result of combining "Omic" technologies to determine relevant genes and metabolic pathways that can serve in marker-assisted breeding to adapt to climate change, this is critical (Zenda et al., 2021). Identification of significant genetic basis for yield, grain weight, flowering time, fiber quality, and disease resistance opens doors for implementing NBTs in breeding and also use of existing genetic resources(Mahmood et al., 2022). Moreover, when the field is not regulated one, plant phenotyping links breeding and precision farming which are two approaches of a broader strategy needed to have a steady supply of food security (Janni et Pieruschka, 2022).

The amount of data needed on genome sequences, which includes both the pan-genomes of farms and wild animals, as well as the specific identification of alleles and important genes involved in providing the plants with a response to HS stress, and the mechanisms of tolerance, is rather exhaustive. Accurately identifying and characterizing distinct haplotypes will provide the groundwork for genome editing and other genomic-assisted breeding techniques aimed at enhancing resilience in addition to increasing economic yields and sustainability.

Agroecosystems must adapt to climate change via comprehensive measures and a move from reactive to integrated approaches, but on the same scale. Some recommendations in this direction pertain to technical interventions; these include the modification of the use of agricultural amendments, the optimization of precision irrigation techniques, and the use of genomic and phenotypic characterization to produce seed varieties that were more resistant to drought and high temperatures (Mirón et al., 2023).

Resource-saving technologies have to be seen as mitigating technologies in the context of a comprehensive strategy in order to achieve greater sustainability (Ermakova et al., 2021).

By enabling farmers to customize agricultural inputs and management circumstances, precision agriculture technology have the potential to be instrumental in the implementation of Climate Smart Agriculture (Toriyama, 2020). In order to increase sustainability and resource use efficiency, many important technologies are already being used in agriculture. For instance, variable rate application has the potential to significantly reduce N2O consumption, up to 34% (Mamo et al., 2003; Kanter et al., 2019).

Utilizing unique multilayer soil structures (fertile layer, hydro accumulating layer, and sand), irrigation, desalination of salt water through evaporation or reverse osmosis, and the adoption of the circular economy as a component of the global solution are all examples of irrigation (Myrzabaeva et al., 2017; Martinez-Alvarez et al., 2020; Gao et al., 2022). However, rather than only looking for workable answers, the question of how to combat climate change from a circularity viewpoint has gained popularity (Romero-Perdomo et al., 2022).

Novel technologies-based sensors, such as those that are proximal, in vivo, and remote, can greatly improve irrigation efficiency and result in water savings in this context (Janni et al., 2019; Segarra et al., 2020; Tavan et al., 2021; Kim and Lee, 2022). These sensors are becoming increasingly common in daily farm management.

Lastly, and paradoxically, data from the omics approach has highlighted epigenetics—a general word for all causes of variation that go beyond the scope of traditional genetics. Among them are transposons, non-coding RNAs, chromatin control, and chemical modification. The function of non-coding RNAs, such as microRNA (miRNA) in regulating plant response to various abiotic stressors, such as HS (Pagano et al., 2021), and the fact that these miRNAs are a component of the "plant immune system," the innate response to this stress, are two topics of great interest.

The goal of this activity is to shed light on fresh ideas and open up new avenues for communication in order to lessen the devastating impacts of climate change. All things considered, the holistic approach focuses on a number of topics that the general public, policy officials, food producers and farmers, public research organizations, and consumers find interesting. According to this view, omics is a first step toward agricultural sustainability (Braun et al., 2023; Gil, 2023). This essay examines every facet of food production, pointing out the advantages and disadvantages of the existing strategies.

Conclusion

Climate change effect on the agriculture in particular has several dimensions and calls for a holistic approach aims at alleviation and adaptation. Discussing different studies and evaluations the impression is that climatic change including heat stress are the main reasons of global food insecurity and environmental deterioration. Integrating emerging technologies, such as omics (genomics, proteomics, metabolomics, phenomics, and ionomics) at the experimental level helps us in better understanding and response of plants to factors like temperature. These technologies helps in identification of important genes, metabolic pathways and physiological mechanism that are involve with heat stress tolerance and consequently this way this marks the beginning of developing resilience crops for the future.

In addition to the above mentioned innovative agricultural practices such as biostimulants, nanofertilizers and precision agriculture techniques, other promising solutions include strengthening the plant resilience, better managing the resource use efficiency and reducing greenhouse gas emissions. The abovementioned techniques coupled with continuous plant breeding and engineering precision offer a promising way towards overcoming the daunting problems of climate change.On the other hand, pushing to obtain knowledge and skills on developing sustainable agriculture in a new era of climate change is a crucial point for policymakers, researchers, farmers, and consumers. It calls for the design of comprehensive solutions that hinge on endurance, resources conservation, and environment care.

Coping with climate change effects on agriculture does not require an approach but a paradigm shift from the isolated targeted approach to a more comprehensive and interdisciplinary approach. By adopting a wide range of scientific approaches, acknowledging the merits of innovation, and encouraging industry-wide collaboration, we can strive to implement an optimized agricultural system that guarantees food security for the coming generations.

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