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Agricultural Biotechnology Solutions to Mitigate Climate Change

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Abstract: Climate change is one of the most significant concerns of the twenty-first century, with significant implications for agriculture, human populations, and ecosystems. It is caused by human actions that changes the components of the world's atmosphere and, along with variation in the natural climate, resembles time. It threatens the agricultural sector and food security, as severe weather conditions have impacted the productivity of crops globally. Heat waves, hurricanes, and thunderstorms, as well as water flow and moisture, are all affected by climate change. These alterations will have an effect on plant development, biology, and crop yields, eventually resulting in shifts in production areas and the utilization of land, which will threaten the supply of food, especially for small-scale farmers and their livelihoods. As climate change becomes a serious issue in the 21st century, agricultural biotechnology is increasingly considered a means of mitigating its effects. It is considered a successful approach for addressing climate change by producing new, high-yielding, resistant to diseases and weather-adaptive cereals as a substitute in food production. Gene editing, genetic engineering, MAS, and GMO solutions have the potential to allow us to adopt crop varieties that are more resistant to pests and diseases, as well as drought and extreme temperatures, which are caused by climate change.

Keywords: Abiotic Stress, Agricultural Biotechnology, Biotechnology, Climate Change, Gene Editing

1. Introduction

Climate change is the most significant issue of the twenty-first century, and this decade is important for efforts to prevent the most severe impacts on human beings and environments. Global warming, as defined by the United Nations Framework Convention on Climate Change (UNFCCC), is a climate change caused by human actions that changes the components of the world's atmosphere and, along with variation in the natural climate, resembles time. It poses major concerns for food and agricultural safety as severe weather patterns have lowered crop yields globally. Agriculture constitutes one of the socioeconomic aspects primarily vulnerable to climate change, because it depends on the characteristics of soils, weather conditions, and biological diversity [1, 2]. Precipitation, water flow, moisture, and heat are all affected by climate change. Extreme climate and weather phenomena will become more frequent and severe, and the pattern of distribution and availability of species of pests and pollinators could change [3]. These alterations will have an effect on plant development, biology, and crop yields, eventually resulting in shifts in production areas and the utilization of land [4].

1.1. What Factors Contribute to Causing Climate Change

Our environment is constantly shifting and changing. The weather has been drastically shifting over the past 100 years or so, resulting in an ongoing upsurge and decrease in rainfall and temperature patterns. Climate change is primarily caused by two factors: both man-made and natural (anthropogenic activity) (Figure 1). Our activities have created this drastic shift, which has led to a rise in the level of carbon dioxide in the environment.

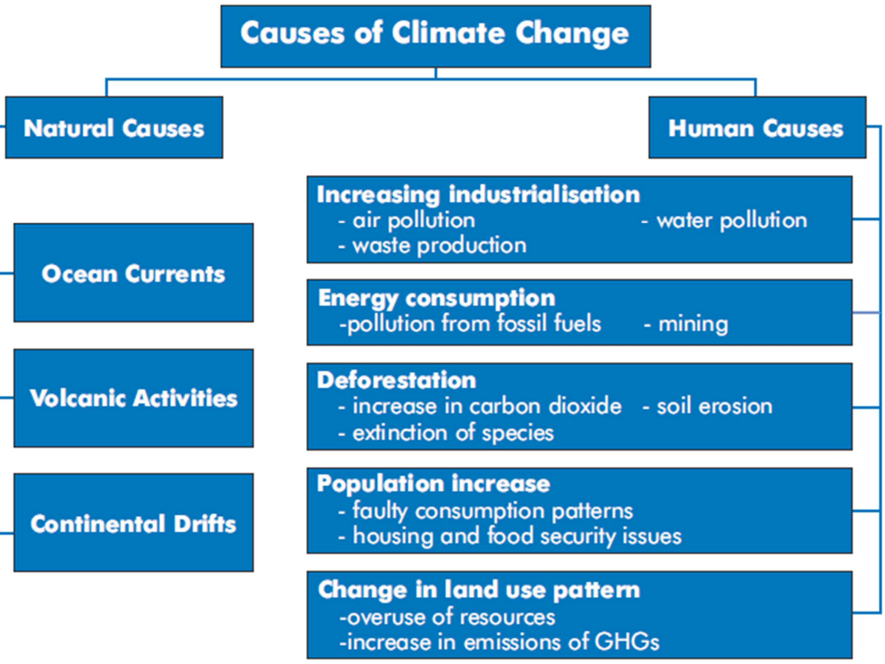

Figure 1. *Cause of climate change.*

1.2. What Impact Does Climate Change Have

Climate change has different impacts around the world. Weather change has been shown to pose more problems for less developed nations. Scientists suggest that global warming at this level currently exists and may yield the following outcomes: shifts in precipitation (quantity and pattern), a greater frequency of catastrophic storms such as heat waves, hurricanes, tornadoes, and thunderstorms, a longer time of ongoing and more serious droughts, the development of subtropical arid regions, species risk, extinction, and a decrease in biodiversity. These factors threaten the supply of food, especially for small-scale farmers and their livelihoods.

1.3. Impacts of Climate Change on Agriculture

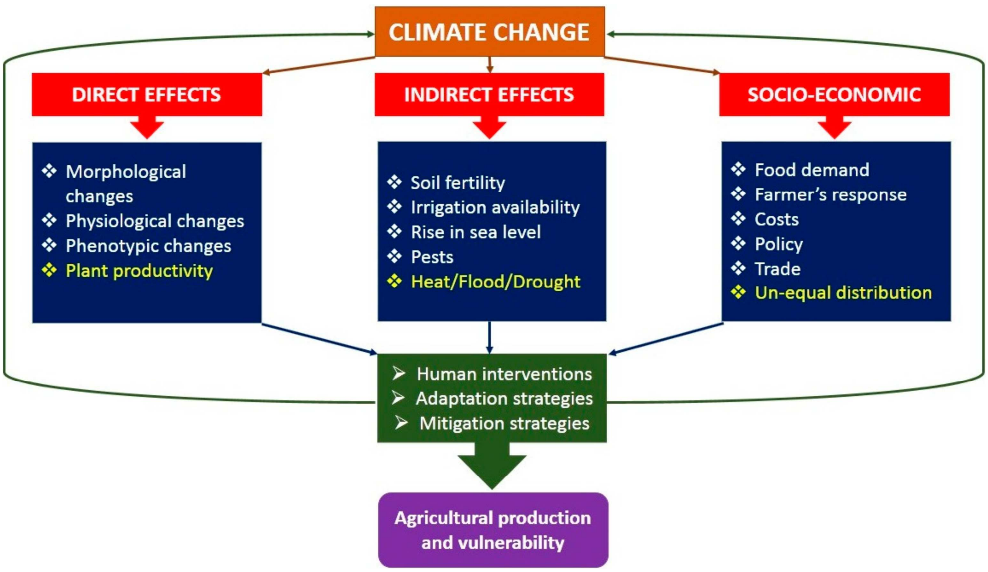

Figure 2. *Impacts of climate change on agricultural production. (Source: Ali Raza et al., 2019).*

Climate change can reduce agricultural output and quality of nutrition owing to severe drought, extreme heat, and flooding as in addition to rising insects and disease of plants. Climate change is causing it more difficult for crop cultivation that satisfies people's needs [5]. The consequences are irregularly dispersed over the planet and are produced by variations in rainfall, temperature, and ambient greenhouse gases concentrations caused by worldwide global warming [6]. Millions of people had been struggling from a shortage of food as a result of climate change in 2019. Furthermore, the expected drop in world production of crops is 2%-6% every decade [7]. In 2019, it was anticipated that consumption costs would increase by 80% by 2050. This is predicted to worsen the insufficient food supply, particularly in regions with greater poverty [8, 9]. According to a 2021 study, the impact of extreme heat and drought on agricultural production across Europe has increased by three times over the past fifty years, ranging from a 2.2% loss in 1964–1990 to a 7.3% loss in 1991–2015 [10]. Climate change has a significant effect on agricultural production, human health, and socio-economics, directly or indirectly (Figure 2).

2. Agricultural Biotechnology

Agricultural biotechnology is the utilization of living organisms or cellular parts in agriculture. Tissue culture, conventional breeding, molecular marker-assisted breeding, genetic engineering, gene editing, and GMOs are all currently in use. Breeding advances enable farming to attain larger yields while addressing the demands of a growing number of people that has scarce resources of water and land. Current biotechnology for agriculture involves technological processes that go beyond normal breeding barriers to manipulate genetic material and fuse cells. The best-known instance is genetic modification, which uses "transgenic" technology to make genetically engineered organisms, or GMOs, by inserting or deleting genes. Genetic engineering, often known as genetic transformation, is the artificial modification of genetic material. It entails isolating and editing a genome at a specific place with specific proteins. The targeted pieces of DNA may be later delivered to the living tissues of the target organism. The use of the bacterium Agrobacterium tumafaciens as an agent for conferring gene characteristics is a common practice in genetic engineering [11]. The ballistic impregnation technique is a more recent technology in which DNA is linked to a tiny golden or tungsten-based particle and activated into plant tissue [12]. Plants can be genetically modified to improve flavor, resilience to diseases and insects, or develop in extreme climates. In this decade, the biosafety and genetic modification processes in Africa have been formed with the goal of introducing GM organisms into Africa's agricultural practices. South Africa, Egypt, and Burkina Faso have currently introduced genetically modified organisms, and numerous other nations have established the ability to perform studies and experiments in contemporary agricultural biotechnology [13]. The term "green biotech" refers to the application of ecologically beneficial remedies in farming, cultivation, and livestock rearing techniques [14].

3. Agricultural Biotechnology Applications to Mitigate Climate Change

3.1. Gene Editing

Climate change has imposed significant limits on agricultural productivity, prompting the development of gene editing-based solutions. Gene editing allows for specific alteration of the crop genes, speeding the development of novel cultivars capable of withstanding the challenges of climate change in addition to collecting and preserving excess carbon dioxide in the atmosphere. The use of gene editing in crops to increase environmental strain, salinity tolerance in rice, drought tolerance in rice, drought tolerance in maize, yield increase, abiotic stress tolerance, and pest and pathogen resistance.

3.1.1. Increasing Abiotic Stress Tolerance

Drought, salinity, and flooding are among the most significant risks to agricultural output in the face of climate change. Climate change is projected to exacerbate the effects of abiotic stress on food production systems. Previous study work show that gene editing is a great technique for expanding plant compassion, as indicated in the scenarios following (Table 1).

Table 1. *Summary of gene editing application for abiotic stress.*

Species	Trait category	Trait targeted	Gene(s) Edited*	Method	Year of published	References
Banana	Abiotic stress	Semi-dwarfed	Ma04g15900 Ma06g27710 Ma08g32850 Ma11g10500 Ma11g17210	CRISPR/Cas9	2019	(Shao et al., 2020)
Maize	Abiotic stress	Drought tolerance	ARGOS8	CRISPR/Cas9 20	2016	(Shi et al., 2017)
Rice	Abiotic stress	Drought Tolerance	EPFL9	CRISPR/Cas9, CRISPR/Cpf1	2017	(Yin etal., 2017)
Rice	Abiotic stress	Early flowering	Hd2, Hd4, Hd5	CRISPR/Cas9	2017	(Li et al., 2017)
Rice	Abiotic stress	Salt tolerance	OsRR22	CRISPR/Cas9	2019	(Zhang A. et al., 2019)

3.1.2. Salinity Tolerance in Rice

Rice, which is an essential diet for over half of the worldwide human population, is critical for worldwide nutritional stability [15]. Drying and saline are both key abiotic elements that impact rice, necessitating studies on the possible use of editing genes to generate resilient cultivars. CRISPR/Cas9 was utilized to delete OsRR22, a locus linked to salinity vulnerability in rice [16]. Rice development in high-salinity conditions (0.75% NaCl) was enhanced, whereas grain yield, biomass from crops, and grain quality were not affected. Modified strains are 19 percent shorter in a saline mixture, while wild-type varieties are 32 percent shorter. Gene edited plants likewise had considerably fewer mass decreases owing to salty exposure than unedited plants, and there were no notable variation when saline was not present. Salinity tests were undertaken on the greenhouse gases, and general agro-efficacy was examined in the actual field. In comparison with wild-type crops, altered plants experienced considerably less serious salt-induced biomass losses [16].

3.1.3. Drought Tolerance in Rice

Rice has been genetically modified to improve drought and high-temperature tolerance through stomatal development. Stomata, anatomical features on the surface of all crop plant tissues, are the primary sites of water loss. While this study did not explicitly test the effects of this editing on water use efficiency, other research has shown that stomatal reductions in rice have clear, positive implications for water use efficiency [17]. Despite no differences in yield, rice lines with lower stomatal densities had higher yields in severe drought and were able to maintain lower temperatures. Thus, by reducing stomatal densities through gene editing or cisgenic approaches, plants may be able to withstand water deficits while also increasing heat tolerance.

3.1.4. Drought Tolerance in Maize

Gene editing technologies, besides generating knockouts, may additionally enable knock-ins. To increase drought tolerance, researchers utilized CRISPR/Cas9 to introduce a transcription factor at a particular corn locus to boost drought tolerance [18]. Another maize regulator has been specifically placed into ARGOS8, a drought adaptation gene. This exact insert allowed for increased crop productivity despite blooming stress from water while preserving typical development returns. This is a genome editing-enabled intragenic approach in which a native maize genetic code is inserted at an unknown region to improve crop responses to an abiotic stressor.

3.1.5. Yield Increase and Abiotic Stress Resistance

A preliminary effective CRISPR/Cas9-mediated deletion of genes method aimed at targeting environmental stressors in African sorghum cultivars and Cowpea to target environmental stresses has been described [19]. In recent years, genome editing has been employed to focus on an identifiable DNA in yams, potentially allowing for quick advances by avoiding the yam's lengthy developing period [20] and creating environmentally friendly banana varieties that have several and long-lasting barriers to severe weather and dry conditions [21]. Maize researchers employed CRISPR/Cas9 to create cultivars resistant to dehydration, disruption of DNA, and oxidative damage via modifying the gene expression of poly (ADP-ribose) polymerase (PARP), which is crucial for maintaining energy balance under stressful circumstances [22]. Scientists additionally proved how editing genes might be utilized to target and enhance the production capacity of Kabre rice, aiding the cultivation of African rice landraces [23] In a similar way, evidence of principle for the application of gene editing in the production of drought-tolerant wheat varieties is being created. The project will use CRISPR-Cas9 to knock out the Sal1 genes in wheat to examine if drought tolerance improves in sal1 mutant wheat plants [24, 25].

3.1.6. Increasing Crop Yields Through Improved Weed Control

Crop yield increases, such as decreased waste, allow producers to generate higher-value products without raising expenditures proportionally. The primary obstacle to improved production is noxious weeds, but pests, diseases, and drought are also problems. The application of genome editing to reduce weeds might result in significant greenhouse gas savings per unit gained. The development of this method is aided by genetically modified herbicide-tolerant (HT) crops. In fact, HT agricultural products have been found to be so advantageous compared to conventional weed-control strategies that they now account for a significant portion of corn, cotton, and soybean crops in the United States, as well as similar substantial amounts of commercial access in almost every nation when authorities permit them for cultivation [26].

3.1.7. Pest and Pathogen Resistance

Crops become increasingly prone to biological pressures such as insect, fungal, and bacterial pathogen attacks as abiotic factors and environmental stresses rise [27]. Increases in temperature will additionally boost the frequency and location of several pathogenic organisms. Genes that confer resistance from non-elite varieties or wild relatives are generally crossed with commercially produced cultivars to create fungal and bacterial pathogen-resistant varieties of crops [28]. Backcrossing the hybrids to the vulnerable progenitor for many years' results in resistance to disease and superior genetics. These crossing processes may require up to ten years for certain species, which is extremely sluggish given the speed at which the environment is altering. By altering genes critical for resistance to disease and reaction, gene editing has generated tolerance to fungus pathogens of wheat [29] and bacterial pathogens of rice [30] in as little as a year. It is possible to envision futures where gene editing substitutes for the existing challenging ways of producing plants that are resistant to diseases.

3.2. Marker Assisted Selection

The process of generating interesting plant forms involves multiple processes and may require anywhere from ten to twenty-five years, depending on the plant being grown. Nevertheless, agricultural biotechnology has considerably reduced the time required to get those products to consumers. Right now, generating novel plant types requires seven to ten years. Marker-assisted selection (MAS) is one of the strategies that researchers employ to make it simpler and more quickly possible to pick crop characteristics. The application of molecular markers in the breeding process can assist breeders in identifying traits that influence features that are successful in enduring stresses, eliminating the requirement for profiling and minimizing field evaluations [31]. Other applications of molecular markers include finding and discovering genetic diversity and the possibility of marker-assisted selection (MAS) under stress conditions [32, 33]. In the majority of crops, once genes and markers for a given characteristic have been identified, molecular marker-assisted breeding, an agricultural biotechnology tool, has become an ordinary process in selection. This approach has been employed for effectively transferring key genes into diverse crops, including bacterial disease resistance in rice, improved beta-carotene content in rice, cassava, and banana, and rice submergence tolerance [34]. Genetic markers can also be utilized to determine the genetic makeup of a line or species. Random primers are utilized in molecular approaches that analyze the genetic composition of the crop being studied. Information is entered into a computer program that analyzes the relationship of a single line to another. The genetic variation of these lines is used for selection for significantly distant parents and is beneficial for the development of hybrid seed technology. The information will also include insights on the line's descent, potential qualities, and the crop's distinctive identification, which will be important for the creation of germplasm databases.

3.3. Genetically Modified Crops

The use of GM crops may assist in reducing agricultural-related emissions of greenhouse gases. Gains in GM yield could lower emissions from production while simultaneously reducing changes in land use and associated pollutants. Increased utilization of already-existing genetically modified crops throughout Europe might result in a 7.5 percent reduction in overall agriculture greenhouse gas emissions. Some research has also found that particular genetically modified crops help decrease greenhouse gas emissions while encouraging carbon storage in the ground by allowing for less intensive agriculture [35, 36]. Crop yield enhancement may lower the necessity of additional land to be used for cultivation as worldwide consumption of agricultural products grows, eliminating further carbon dioxide emissions from changing the use of land. Currently, changes in land use contribute to greater than thirty percent of all agricultural greenhouse gas emissions [37]. While several GMO characteristics have already been created, the two most commonly utilized are insect resistance (IR) and herbicide tolerance (HT), both of which are utilized to reduce crop damage caused by both pests and weeds, hence improving overall productivity. A worldwide meta-analysis found that the typical production advantages of genetically modified crops are 22 percent, with some variations depending on characteristics and regions [38]. In temperate-zone industrialized countries, the typical yield improvements following the adoption of genetically modified crops are ten percent and seven percent, respectively, for IR and HT. When agricultural biotechnology studies advance, a broader range of characteristics with variable yield consequences will become available. GM crops that are resistant to pressures like dryness and warmth, such as IR and HT, can boost useful production by reducing losses to crops. GM characteristics that enhance the potential for yield via enhanced plant growth and photosynthetic efficiency could result in higher yield increases.

3.4. Genetic Engineering

The manipulation of genetic materials in living organisms for the purpose of generating genetically modified organisms, or GMOs, or transgenic organisms is an organism that, using the recombinant DNA and gene-splicing methods of the field of biotechnology, enables itself to carry out particular activities that were not previously possible with traditional breeding techniques (39, 40]. This method offers a quicker and more effective means to get the desired features. Furthermore, many current studies that have carefully evaluated genetic engineering-based biotechnology have demonstrated remarkable advancements within the past two decades in altering the genes in microorganisms and plants to provide pest and disease resistance, herbicide resistance, and drought tolerance [41] and generate important genetically modified crops in terms of nutrition through decreasing saturated fats and increasing the levels of unsaturated fatty acids, thereby expanding bio-control agents [42]. As a result, more efforts must be made to educate the public about the advantages of biotech in enhancing productivity in agriculture, ensuring food security, and minimizing global warming effects.

4. Conclusion

Agriculture is the primary source of food and income, especially in areas vulnerable to climate change. Climate change has both immediate and long-lasting effects on many steps in food systems [43], but crop production suffers the most. It is a serious threat to the environment's future, affecting food production, ecosystems, the lives of humans, and practically every aspect of our planet. An approach to the safe application of modern agricultural biotechnologies will increase yield and food security while also making a significant contribution to climate change adaptation. This measure contributes to increased agricultural productivity while also protecting the ecosystem from extreme weather events.

Conflict of Interest

The author has not declared any conflict of interests.

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