**Modern biotechnology for climate change adaption of crops**

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**Abstract**

Climate change is caused by the emission of greenhouse gases over the years and negatively affected the environment and decreasing the agricultural production and productivity. Emission of carbon dioxide and other greenhouse gases from human activities, animal husbandry, and primary burning of crop residues are the major causes of climate change. Biotechnology can positively reduce the effects of climate change through modern biotechnology. Therefore, climate change is the very serious issue on earth which needs to be focused for better and sustainable agriculture. The current challenges and future perspectives of modern biotechnology for climate change adaption of crops are highlighted. Conventional biotechnology approaches such as reduced use of artificial fertilizer, energy efficient farming, tissue culture and conventional breeding strategies for adaptive varieties are among feasible options that could positively reduce the negative effect of climate change. Though the modern biotechnology approaches the climate ready crops are developed which is resistant to the various biotic and abiotic stresses. Both the conventional and modern biotechnology approaches will significantly play a very important role in current and future worldwide climate change adaption of crops.

**Key words:** Adaptation, Biotechnology, Climate change, Mitigation, Carbon sequestration, Bio-safety

1. **Introduction**

Intergovernmental Panel on Climate Change (IPCC) described that climate change is the mean change or variability of its properties for a long period. “Climate change” is defined as a significant changes in long-term (more than 30 years) climate status [1]. According to the IPCC report, climate change is mainly caused in two ways one is anthropogenic which includes changes in land use by human being action and another one is natural forces like the accent of solar cycles, volcanic eruption, and continental drift [2]. Two main causes lead to changes in climate i.e. changes in the earth’s orbit, gases in the atmosphere, and anthropogenic influences. Different types of atmospheric gases have the property to absorb the part of the solar radiation reflected by the earth’s surface. These gases include greenhouse gases (GHGs) which will prevent radiation from being into space and cause warming in the atmosphere. Greenhouse gas emission is mainly due to industrial development and other activities including carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6) [3]. The climate changes that may occur due to increased CO2 concentrations, could lead to pest and disease outbreaks often disregarded in enrichment studies [4]. Agriculture is always considered a climate-based economy with certain regional characteristics, as agriculture often relies on the selection of crops suited to the climate of a region. According to the Food and Agriculture Organization's (FAO) recent report on crop prospects and food situation, if current GHG emissions and climate change trends continue, there will be an increase in the frequency of extreme weather conditions, leading to increased pest and pathogen incidence, abiotic stress, and crop yield reductions in many major crops. Several strategies are being used to try to improve agricultural adaptation capacity by producing tolerant crop types. Conventional plant breeding strategies rely on plants' ability to acquire robust characteristics from wild relatives [5]. Biotechnological methods are comparatively faster and more precise methods used to develop genetically improved climate-ready crops utilizing modern genetic engineering techniques [6]. Plant breeding and crop improvement have been revolutionized through recent techniques of genetic engineering. The creation of high-yielding better-adapted crop varieties that are resilient to climate change is achieved through various tools like genomics-assisted breeding, next-generation sequencing methods, and genome editing [7]. Climate change may be controlled by using fossil fuels, reforestation, and lowering greenhouse gas emissions, among other things [2]. The world populations increase day by day and to feed this increasing population need to increase agriculture production. To overcome this global problem there is a need for a special effort and adapting the biotechnological tools is the special route for this. Thus, biotechnology might help to mitigate the effects of climate change by reducing greenhouse gas emissions and adapting crops to biotic and abiotic stresses [3].

1. **Agricultural Biotechnology**

Fermentation methods, tissue culture, mutation and recombinant DNA techniques, genomic research, the use of molecular markers for breeding, and genetic modification utilizing transgenes are all examples of agricultural biotechnology. Tissue culture is the modern technique of agriculture biotechnology that includes the culturing of cells, organs, and tissues on a nutrient medium under aseptic conditions for the production of disease-free planting materials and other useful products through this *in-vitro* technique [8]. Through advanced breeding methods higher yields can be achieved and it fulfills the needs of the world's increasing populations. Marker-assisted breeding is the modern agricultural biotechnology tool that is already used in a molecular breeding program for most crops where the gene and marker for the specific trait are already known. Marker-assisted breeding is efficiently used in the introgression of important genes into different crops including bacterial blight resistance in rice, increased beta carotene content in rice, cassava, and banana, *fusarium* wilt resistance in chickpea, and submergence tolerance in rice, etc. Genetic engineering is a contemporary agricultural biotechnology tool based on recombinant DNA technology. It entails modifying an organism's genetic composition with "recombinant DNA technology." This involves the use of specialized enzymes to cut, insert, and modify DNA fragments containing one or more genes of interest. Transgenic can be created by modifying individual genes and transferring genes between animals. There is a significant advancement in these technologies, where genes from many sources may be modified and transferred into microorganisms and crops to impart resistance to pests and diseases, tolerance to herbicides, abiotic stressors, and many other benefits. Thus, the function of biotechnology is critical in the context of changing climate and food security, particularly in developing countries.

1. **Biotechnology for climate change adaptation of crops**
2. **Green House Gas Reduction**

Agricultural practices such as synthetic fertilizer usage, rice crop production, overgrazing, and deforestation produce 25% of greenhouse gases (carbon dioxide, methane, and nitrous oxide) emissions into the environment. Biotechnology is one of the most dependable solutions for mitigating climate change through energy-efficient farming, carbon sequestration, and reduced use of synthetic fertilizers [9].

1. **Use of environmentally friendly fuels**

Agricultural techniques play a major role to overcome the negative impact on agricultural production and the environment. The transport sector produces the CO2 and we can overcome this CO2 emission through the production of biofuels, both from traditional crops and GMO crops such as sugarcane, oilseed, rapeseed, and jatropha [9]. Bioethanol and biodiesel increase farming system efficiency instead of fossil fuels. Energy-efficient farming will consequently utilize machinery that runs on bioethanol and biodiesel rather than traditional fossil fuels. Green energy programs based on perennial non-edible oil-seed producing plants will aid in the cleaning of the atmosphere and the production of biodiesel for direct use in the energy sector, or in blending biofuels with fossil fuels in certain proportions, thereby reducing the use of fossil fuels to some extent [10].

1. **Fewer fuel consumption**

Organic farming consumes less fuel due to the use of composting and mulching techniques, which minimize weed and pesticide spraying due to less ploughing [11]. Reduced irrigation would also lead to lower gasoline use, lowering CO2 emissions into the environment. Modern Biotechnology such as genetically modified organisms and other related technologies facilitates less fuel consumption by decreasing the necessity and frequency of spraying and reducing ploughing. Insect-resistant GM crops reduce fuel consumption and CO2 production by reducing insecticide application is the best example [12]. Application of biotechnology reduces fuel usage amounted to savings of about 962 million kg of CO2 emitted in 2005, and a reduction of 40.43 kg/ha or 89.44 kg/ha CO2 emission while the adoption of reduced tillage or no tillage practices due to less fuel consumption respectively [13].

1. **Use of energy-efficient farming**

Green biotechnology has been utilized to help eradicate world hunger by employing several technologies that allow the generation of more fruitful and resistant plants to both biotic and abiotic stress. This technology allows using of less environmentally friendly energy and fertilizer and the practice of soil carbon sequestration. The production of biofuels from both traditional and GMO crops such as oilseed, sugarcane, rape seed, and jatropha would aid in reducing the negative impacts of pollution caused by the transportation industry [9]. Efficient farming will therefore aid in the purification of the environment by the planting of perennial non-edible oil seed. As a result, become actively involved in the manufacturing of biodiesel for direct use in the energy industry. Then it is blended with fossil fuels, which helps to minimize carbon dioxide emissions [14], [15].

1. **Carbon sequestration**

Carbon sequestration is the capture or uptake of carbon-containing substances like carbon dioxide (CO2). Carbon sequestration describes any increase in soil organic carbon content caused due to change in land utilization, with the implication that the increased soil carbon storage mitigates climate change [16]. Therefore, soil carbon sequestration is one of the important strategies to mitigate the increasing CO2 concentration in the atmosphere. Enhancement of carbon sequestration is possible by reducing the traditional tillage operation. Agriculture residue is leaving at least 30% on the land surface; agriculture reduces loss of the CO2 concentration from agriculture and it plays a very important role in reducing water through evaporation, increasing soil stability, and crates he cooler soil microclimate. Different soil conservation practices help to reduce soil erosion, and may also sequester soil carbon and enhance methane (CH4) consumption [17]. According to [16], the climate change advantage of increased soil organic carbon from improved crop growth (for example, through the use of industrial fertilizers) must be weighed against greenhouse gas emissions from the manufacturing and use of such fertilizers.Genetically modified Roundup Ready (herbicide resistant) soybean technology leads to the sequestration of 63,859 million tons of CO2 in the United States of America (USA) and Argentina [18]. The need for tillage or ploughing can be reduced through the use of modified crops. This practice improves soil quality and stores more carbon in the soil, which helps to mitigate climate change [13].

1. **Reduced use of artificial fertilizer**

The use of artificial fertilizer in agriculture systems has led to contamination of the environment with harmful toxic chemicals. When synthetic fertilizers interact with common soil bacteria, they contribute to the creation and release of certain greenhouse gases (N2O) from the soil to the surrounding environment. Artificial fertilizers such as ammonium sulphate, ammonium chloride, ammonium phosphates, sodium nitrate, and calcium nitrate are responsible for the formation and release of different greenhouse gases into the surrounding environment [13]. The negative effect of artificial fertilizers can be reduced by using eco-friendly biotechnology-based fertilizers.

1. **Biofertilizers**

Biotechnology has the potential to minimize the need for artificial fertilizers. In modern biotechnology *Rhizobium* inoculants are improved using mutation or genetic engineering techniques have resulted in improved nitrogen-fixing ability [19]. It also includes the formation of nodular structures on the roots of cereal crops such as rice and wheat, which bodes well for the ability of non-leguminous plants to fix nitrogen in the soil [20]. Another route is the cultivation of GM crops that use nitrogen more efficiently as compared to non-GM crops. An example of GM crops is the nitrogen-efficient GM canola which reduces the amount of artificial fertilizer that is lost into the environment or mixed into soil and water sources and it also impacts positively on the farmer's income through improved profitability [9]. Soil nitrogen management that matches crop demands can minimize N2O emissions and avoid negative effects on water quality. Manipulation of animal feed and waste management can also help to minimize CH4 and N2O emissions from animal husbandry [17].

1. **Biotechnology for crop adaptation to environmental stress**

Climate change decreases crop yield due to insufficient rainfall, the emergence of potential weeds, pests, and diseases caused by fungi, bacteria, and viruses (Table 1). One conceivable strategy to respond to such a worldwide challenge is to use agricultural biotechnologies that prevent the negative consequences of such changes by offering new options for developing stress tolerance [21].

**Table 1: Conventional biotechnology approaches for climate change mitigation**

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| --- | --- | --- | --- |
| **Measure climate change** | **Biotechnology** | **Application** | **Reference** |
| Climate change mitigation: Reduced use of fertilizer | No-till practicesAgroforestry | Coffee and banana and horticultural farmingMycorrhizal and actinorhizal symbiosis | [16] |
| Carbon sequestration | Biofuel production | Bioethanol from sugarcaneBiodiesel from jatropha, palm oil | [10] |
| Adaptation to climate change:Adaptation to biotic and abiotic stresses | Tissue cultureAgroforestry | Drought-tolerant sorghum, millet, sunflower Shading coffee and banana plantations. | [22] |

**Table 2:** **Modern biotechnologies for climate change Adaptation and mitigation**

|  |  |  |  |
| --- | --- | --- | --- |
| **Measures to combat climate change** | **Biotechnology** | **Application** | **Reference** |
| Less fuel consumption | Engineer reduce herbicide resistance, reduce spray | GM soybean, GM canola | [18] |
|  | Engineer insect protection, reduce spray | Cotton, Bt maize, and eggplants | [23] |
| Reduced fertilizer uses | Engineering nitrogen fixation | Genetic improvement of Rhizobium;Reduced nitrogen fixation for non-legumes | [20] |
| Carbon sequestration | No-till farming due to Biotechnological advances Green energy Nitrogen- efficient GM crops | Herbicide-resistant GM soybeans,canola GM energy crop N-efficientGM canola | [10], [17], [18], [24] |
| Adaptation to climate change. | Molecular marker helps for stress resistance by marker assisted breeding | Drought-resistant maize, wheat hybrids | [25] |
| Adaptation to biotic and abiotic stress | Engineering drought salt and heat tolerance. | GM tomato, rice | [21] |
| Improved productivity per unit areaof land | Increased crop yield per unit areaof land | Fungal, bacterial, and viral-resistant GM cassava, potatoes, bananas, maize, canola | [26] |

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1. **Adaptation to biotic stresses**

Development of genetically modified plants that is resistant to the different biotic stresses like insect, bacteria, viruses, and fungi that could reduce the crop yield. *Bacillus thuringiensis* (*Bt*) gene has been introduced into major crops like corn, cotton, soybean, and canola it gives resistance to insects, and pests such as European corn borer, and American pink boll warm but does not have harmful effects on the human and the environment. Genetically Modified crops play a very important role in integrated pest management. The herbicide-tolerant trait has been introduced into corn, soybeans, and canola. Also being developed and commercialized are genetically engineered potatoes, cassava, and other crops that are resistant to biotic stressors [27].

1. **Adaptation to abiotic stresses**

Abiotic stresses like salinity, drought, extreme temperatures, and oxidative stress affect agricultural production and climate. Plant biotechnological methods along with conventional breeding approaches are an important approach for abiotic stress tolerance in crops. These approaches include the selection and growing of drought resistance crops thus allowing their growth in harsh environmental conditions on marginal lands [3].

1. **Agro-ecology and Agroforestry**

The consequences of global climate change, which are altering temperature and precipitation patterns, are affecting agriculture in many tropical locations. Shade management in crop systems, for example, may mitigate the effects of extreme temperature and precipitation, reducing the ecological and economic vulnerability of many rural farmers and improving agroecological resistance to extreme climate events [28]. Mycobiotechnology is the fungal application in biotechnology used to solve environmental problems and restore degraded ecosystems. Mycoforestry and mycorestoration are growing fields of study and application for the regeneration of damaged forest ecosystems [29]. Woody plants such as casuarinas (*Casuartna* sp) and alders (*Alnus* sp.) can fix atmospheric nitrogen symbiotically with actinomycete bacteria (*Frankia* sp.), this phenomenon is beneficial to forestry and agroforestry [30]. Endo- and ectomycorrhizal symbiotic fungi, as well as actinomycetes, have been employed as inoculants in forest regeneration [31].

1. **Biotic crops adapted to climate change**
2. **Rice**

Rice is the first staple food crop in most developing countries, and it is a major cereal crop used in research work. Research-based on 227 adequately watered fields predicted a significant negative impact on rice output owing to projected warmer temperatures [32]. Therefore, efforts have been made to improve rice crops with climate-ready characteristics leading to better performance under different stress environments [7]. Transgenic rice has been developed in terms of improving drought-resistant characteristics and expressing the *Capsicum annum* methionine sulfoxide reductase B2 (*CaMsrB2*) gene, which is drought tolerance at the growth and reproductive stages of the plant [33]**,** is considered as one of the important findings. Several toxic aldehydes can accumulate in plants when they are under stress such as chilling, drought, and salinity [34]. During stress conditions in plants, methylglyoxal known as a cytotoxic metabolite has been accumulated. It has been discovered that preventing methylglyoxal buildup is a potential strategy to increase plant stress tolerance, such as rice responses to low temperature, salinity fluctuations, heavy metals, drought, and submerged conditions. Therefore, genetic manipulation of the glyoxylate pathway has been successfully used in rice, resistant to various biotic and abiotic stresses [35]. The RNAi approach was employed to inhibit RACK1 gene expression in rice, and the involvement of RACK1 in drought responses was discovered [36].

Global warming increases the frequency and intensity of flooding and therefore the production of cereal crops such as rice, wheat, and maize with the ability to withstand the water-logging and extended submergence conditions is important. Three non-SUB1 QTLs were found from IR72 in rice, suggesting that alternate routes may exist apart from the ethylene-dependent mechanism of the SUB1 gene [37]. Salinity tolerance QTL has been mapped on rice chromosome 1, named as *SalTol*, and several salt-tolerant varieties such as BR23, BRRI dhan40, BRRI dhan41, BRRI dhan53, and BRRI dhan54 have been released [38]. In terms of tolerance to biotic stressors, numerous nations have developed genetically modified rice lines that incorporate the Bt gene from *Bacillus thuringiensis* [39]. The chimeric expression of the Bt gene *cry2Aa* and *cry2Ac* were found to be effective against rice leaf folders in rice plants [40]. CRISPR-mediated knockdown of *gna1a, dep1,* and *gs3* genes are found to be involved in the development of climate-ready rice [41].

1. **Maize**

Maize, the second most significant grain crop in roughly 125 developing nations, is to produce around 1040 million metric tonnes globally from 2016 to 2017 [42]. The reduction of its growth and yield due to climate change such as drought conditions and drought stress alone is reported up to 37% yield loss. The genetically modified maize i.e. “MON87460” was developed through transgenic technologies and this is popular development against drought. This transgenic maize includes the expression of cold shock protein B to maintain cellular functions under water stress conditions, preserving RNA stability and translation [43]. The hybrid maize "DroughtGardTM" was produced based on transgenic maize, bred, and released for cultivation in the United States in 2013 to conserve water for cultivation by decreasing leaf development, particularly during the key blooming stages [44]. The improved maize showed less wilting and maintenance of photosynthesis with a 50% increase in grain yield in drought conditions [45]. *AP2, bZIP, NAC, HD-Zip, and MYB* are the drought-responsive transcription factors that have been identified to play an important role in maize drought tolerance [46]. In maize flooding or water-logged conditions are another possible consequence of climate change that most cereal crops are highly susceptible to. If Mize is compared with other crops it is relatively sensitive to flooding and Multiple QTL-related studies are carried out in maize to locate the resistance genes [47]. The putative V-ATPaseA coding area from Western maize rootworm (war) was exploited to create insect-resistant maize utilizing RNAi technology. The resultant F1 hybrid plants were resistant to or, and it is regarded as an effective management of lepidopteran pests. ZFN and other genome editing methods were employed to improve the herbicide tolerance of the maize gene *ZMIPK1* [48], [49].

1. **Soybean**

Soybean is one of the important crops that can be used as food for human and animal consumption. Soybean is a good source of oil for industrial purposes and has made itself one of the main targets in crop improvement programs [50]. However, its production and seed quality are mainly affected by the range of various biotic and abiotic stresses [51]. Among the different abiotic stresses, drought results in approximately a 40% reduction in the growth and development of the plant [21]. The drought-susceptible soybean variety BR16 was transformed with the *AtDREB1A* gene in the drought-inducible promoter *rd29A* of *Arabidopsis thaliana.* Its overexpression improves drought tolerance in soybean by boosting plant photosynthetic rate, chlorophyll content, and stomatal conductance [52]. Roundup-ready (RR) soybean variety developed and commercialized and registered under trademarks of Monsanto Technology LLC [53]. The expression of the 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) gene from Agrobacterium spp. strain CP4 makes RR crops resistant to the herbicide glyphosate [54]. [55], in 2014 reported that the expression of the *cry1Ab* gene plays an important role in the prevention of larval feeding and growth of *Anticarsica gemmatalis.* Several studies have revealed that the expression of the synthetic *cry1Ac* gene causes full larval death in *Anticarsia gemmatalis* while lowering larval survival in *Pseudoplusia* included and *Helicoverpa zea* [56].

1. **Wheat**

Wheat is one of the most important crops that contribute to global food security and is the major food source for more than 50% population of the world. It is sensitive to abiotic stress like water scarcity, and the yield of this crop is compromised in drought stress conditions [57]. In India alone, the loss due to the impact of climate change and associated water scarcity is declining by up to 2 million [58]. Seed germination is affected by increased temperature and increases the risk of failure. The activation and regulation of certain stress-related genes form the basis of molecular regulatory mechanisms for abiotic stress tolerance. The metabolism and signaling of growth regulators like abscisic acid and gibberellic acid can be thought of as a turning point in terms of wheat seed germination, therefore it is vital to understand the temperature-dependent molecular mechanisms that may affect the seed germination [59]. Further, the transcription factors are also investigated in improving the water stress of crops. One of these, the dehydration-responsive element binding (*DREB*) gene, was introduced into bread wheat by biolistic transformation and put under the control of a stress-inducible promoter from the *rd29A* gene [60]. [61], in 2001 reported that in terms of plant's resistance to salt stress conditions, salt-tolerant plants also often tolerate other abiotic stresses including chilling, freezing heat, and drought and such high-performing genetically modified wheat plants have been developed worldwide. The evaluation and identification of the QTLs of 150 winter wheat cultivars revealed SNPs in 37 quantitative trait loci linked to the salt tolerance features. These have been useful in improving wheat, and it is anticipated that found polymorphism will be exploited in the next breeding programs [62]. Improvement of aphid resistance is done through the manipulation of the transgene *Pinellia pedatisecta agglutinin* (*PPA*), TALEN, and CRISPR-mediated genome editing tools used to improve wheat powdery mildew resistance by manipulating the target gene *TaMLO* are highlighted [63]. Some of the most effective alterations in the world are *TaGASR7* gene editing for increasing grain length and weight [64] and PDS gene editing for increasing plant chlorophyll production [65].

1. **Barley**

After rice, maize, and wheat, barley is considered the world's fourth most significant cereal crop. Among these, barley is emphasized as a crop that may be adapted to abiotic challenges in a relatively short time [66]. Because of barley’s natural stress tolerance, researchers are increasingly interested in identifying stress-sensitive genes using different small/large-scale omics investigations, comparative genomics, and genetic transformation to overexpress some of these genes [67]. Abscisic acid is thought to be involved in various metabolic processes that contribute to plant drought, salinity, and cold tolerance [68]. ABA and various abiotic stimuli have been shown to activate the *H. Vulgare* abundant protein 1 (*HVA1*), and overexpression of *HVA1* in different cereal plants has been shown to increase tolerance to various abiotic stresses [69]. Several such processes underlying stress-related genetic variation have been studied and found to have a significant influence on the enhancement of barley production when climatic circumstances change [70]. Sequencing and related mapping efforts have been performed on several barley species, with Tibetan hulless barley being highlighted as a resource for furthering barley genomics research [71]. CRISPR/Cas9-mediated editing of *MORC1*, a defense-related gene has been identified in *Arabidopsis thaliana*, and has been used to increase the resistance to both *Blumeria graminis f*. sp. *Hordei*; the cause of barley powdery mildew, and *Fusarium graminearum* in barley. [72] has been identified as the genes responsible for several abiotic and biotic stress resistance in the genome of wild species of barley (*AWCS276*) [72] paving the pathway to several improvements in a barley crop. Identification of important QTLs is also a major concern in crop improvements. The black lemma and pericarp (Blp) loci, as well as the QTLs responsible for resistance to net blotch disease (caused by the fungus *Pyrenophora teres*), have been effectively mapped using exome-QTL sequencing [73]. Several abiotic stress tolerance character such as drought tolerance, submergence tolerance (*SUB1*), and salinity tolerance is governed by QTLs [74]. CRISPR/Cas9 mediated mutation has been reported to decrease callose deposition in sieve tubes, rendering plants resistant to aphid infestations. Molecular markers for key resistance genes and quantitative trait loci (QTL) against numerous diseases in barley have been established, including rust (*Puccinia* spp.) and powdery mildew (*Blumeria graminis f*. sp. *hordei*), *Rhynchosporium commune* [75]. In recent years, the application of developed markers in marker-assisted selection on barley has been regarded scarce. However high-throughput Phenotyping techniques along with NGS are considered to increase the ability to identify loci related to several important traits [7].

**Table 3: Climate-ready crops improved using modern biotechnology**

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| --- | --- | --- | --- | --- |
| **Crop** | **Gene and modern biotechnology methods** | **Target traits**  | **Trait improvement** | **References** |
| Rice | Transgenic rice expressing Capsicum annum methionine sulfoxide reductase B2 (*CaMsrB2*) gene | Drought resistance | Drought tolerance at the reproductive stage | [33] |
| Rice | RNAi silencing of *RACK1* gene expression | Drought resistance | Higher growth even at water stress | [36] |
| ASD India Rice | Transgenic of gene DNA helicase-47 (*PDH47*) from Pisum sativum | Drought resistance | Regulate several stress response genes | [76] |
| Rice | CRISPR editing on MADS-box transcriptionfactors for gene *MADS78* and *MADS79* | Seed germination | Endosperm cellularization and early seed development | [77] |
| Rice | Knockdown of *gna1a, dep1,* and *gs3* gene | Abiotic stress resistance-Climate ready crop | High yield, large grain size, grain number, improved grain weight | [41] |
| Rice | CRISPR edition of 3ʹ end of *OsLOGL5* coding sequence | Drought resistance | Increase in grain yield | [41] |
| Rice | Cytokinin homeostasis | Stress resistance | Increase in grain yield | [78] |
| Rice | CRISPR of *gs3* and *dep1* genes | Salinity tolerance |  | [41] |
| Rice | Silencing the ERF transcription factor gene *OsERF922y* CRISPR editing | Disease resistance | Resistance to rice blast in both seedling and tillering stages | [79] |
| Maize | Transgenic maize preserving RNA stabilityand translation of Cold shock protein B | Drought resistance | Maintain the cellular functions underwater stress conditions | [43] |
| Maize | Transgenic maize with homologous *ZmNF-YB2* | Drought resistance | 50% increase in grain yield | [45] |
| Maize | CRISPR/Cas9 system to edit *ARGOS8* | Drought resistance | Increase in plant yield | [80] |
| Maize | ZFN technique to knock out of TMS5, the *thermo-sensitive male sterile 5* gene | Heat resistance | Thermos-sensitive male-sterile maize crops | [81] |
| Maize | RNAi technology in putative V-ATPaseAcoding region | Pest resistance | Resistant to Western corn rootworm | [48] |
| Soybean | Overexpression of Arabidopsis gene*Δ1-pyrroline-5-carboxylate synthase (P5CR)* | Resistance to drought | Tolerance to high-temperature condition | [41] |
| Soybean | Transformed with *AtDREB1A* gene underrd29A | Drought resistance | Increase in plant photosynthetic rate, plantchlorophyll content with a higher stomatalconductance | [52] |
| Soybean | Virus-induced gene silencing of *WRKY*transcription factors | Stress resistance | Resistant to biotic and abiotic stress | [53] |
| Soybean | Transgenic with *csr1-2* gene from Arabidopsisthaliana | herbicide- resistance | Resistant to imidazolinone chemical class | [55] |
| Soybean | Transgenic with *cry1Ab* gene from *Bt* | Pest resistance | Resistant to larval feeding and growth of*Anticarsia gemmatalis* | [55] |
| Wheat | Dehydration-responsive element binding (*DREB*) gene | Water stress | Tolerance of water stress conditions | [60] |
| Wheat | Transgenic with manipulation in transgene*Pinellia pedatisecta agglutinin* (*PPA*) | Pest resistance | Resistance to Aphid damage | [63] |
| Wheat | TALEN, and CRISPR-mediated genome editing to the target gene *TaMLO* | Pest resistance | Resistance to Powdery mildew disease | [63] |
| Wheat | CRISPR/Cas9-mediated gene editing in *EDR1*gene | Pest resistance | Resistance to Powdery mildew disease | [46] |
| Wheat | CRISPR-mediated editing of gene *TaGASR7* length and weight | Drought resistance | Improved grain length and weight | [65] |
| Barley | Overexpression of *HvSNAC1* stress responsible transcription factor | Drought resistance  | Tolerate drought without a reduction in crop yield | [82] |
| Barley | CRISPR/Cas9-mediated editing of *MORC-1* gene | Pest resistance | Resistance to *Blumeria graminis f. sp. Hordei*  and *Fusarium graminearum* damage | [72] |

1. **Bio-safety policies in modern biotechnology for climate change and food security**

The development of modern biotechnology for climate change adaptation of crops depends on national biosafety policies. Now a day, several countries adopted the Cartagena Protocol on Bio-safety for the Use of modern biotechnology in crops and climate change mitigation [83]. Bio-security and bio-safety systems are key to maximizing the advantages of biotechnology in terms of environmental and health problems that are addressed by scientific risk assessment [84]. For the crops to be released into the environment safely, biosafety rules must be implemented.

Public-private partnerships must be taken into consideration for the effective use of modern biotechnology to mitigate climate change and enhance food security. These partnerships are also required for the regulation and execution of biosafety regulations and to assure biosecurity [85]. The government cannot handle climate change and greenhouse gas emissions alone. The emission of GHGs can be reduced with the formulation of good policies on agricultural development with the use of agricultural biotechnology for the mitigation of climate change. This should be done by following the biosafety laws to ensure there is no harmful effect on the human and the environment. Government bio-policymakers should communicate with university and other institution leaders, as well as farmers, via seminars, community services, workshops, and panel discussions, because farmers need to be informed about the technological potential and management requirements of GM crops [86]. The more enlightened the farmers are, the easier to accept the technology.

According to the industrial perspective, GM foods are safe. The careful application of biotechnology and genetic engineering will improve human health and welfare while saving time and money. A proper risk assessment protocol should be used on GM crops using well-authenticated and up-to-date methods of chemical analysis to estimate the contents of its major and minor components and compare their amounts to those of the corresponding parent line in terms of climate change and health care [87].

1. **Current Challenges and future perspectives**

Climate change has an impact on food insecurity and health safety concerns, and there is no evidence that this will alter shortly; action must be made now to adapt in a timely way. With the world population predicted to reach 9 billion people by 2050, food consumption is expected to rise by 70%, requiring countries to acquire an extra 400 million hectares of cropland [88]. As a consequence, if we are to feed the globe without destroying our resources, science, and technology must drive the development of modern agricultural methods. Modern biotechnology has accepted enormous public debates related to the risk and benefits of transgenic or genetically modified organism (GMOs) technology in terms of environmental, human health, socioeconomic, and ethical and cultural concerns issues. Biotechnology has great potential to increase food production and agricultural productivity, but the risk must not be neglected due to direct changes in the genetic makeup of organisms. Due to the limitations of human understanding, the possibility of unknown dangers cannot be ruled out with absolute confidence, neither for genetically modified or transgenic crops nor for any other technique such as traditional breeding and natural selection [89].

1. **Conclusion**

This chapter shows that safe improvement and application of modern biotechnology can contribute positively towards climate change adaptation of crops through greenhouse gas reduction, use of environmentally friendly fuels, less fuel consumption, use of energy-efficient farming, carbon sequestration, reduced use of artificial fertilizer and Biofertilizers. These measures are intended to boost agricultural output and food security while also safeguarding our environment from the negative consequences of climate change. This can ultimately play a very important role in food security and agricultural productivity, and at the same time protecting our ecosystem from the negative effects of climate change. Specific examples of crops are discussed in their development showing that these measures integrating modern biotechnology can be effectively used to improve the productivity of agriculture of the world. Modern biotechnology has been used to design climate-ready crops.

1. **References**

[1] T. Stocker, *Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge university press, 2014.

[2] N. Nakicenovic, R. J. Lempert, and A. C. Janetos, “A framework for the development of new socio-economic scenarios for climate change research: introductory essay: a forthcoming special issue of climatic change,” *Clim. Change*, vol. 122, pp. 351–361, 2014.

[3] S. Kumar, R. Bansode, and M. K. Malav, “International Journal of Applied And Pure Science and Agriculture,” no. April, 2015.

[4] S. J. Vermeulen, B. M. Campbell, and J. S. I. Ingram, “Climate change and food systems,” *Annu. Rev. Environ. Resour.*, vol. 37, pp. 195–222, 2012.

[5] S. E. Beebe, I. M. Rao, M. W. Blair, and J. A. Acosta-Gallegos, “Phenotyping common beans for adaptation to drought,” *Front. Physiol.*, vol. 4, p. 35, 2013.

[6] R. K. Varshney *et al.*, “Fast-forward breeding for a food-secure world,” *Trends Genet.*, vol. 37, no. 12, pp. 1124–1136, 2021.

[7] T. I. K. Munaweera, N. U. Jayawardana, R. Rajaratnam, and N. Dissanayake, “Modern plant biotechnology as a strategy in addressing climate change and attaining food security,” *Agric. Food Secur.*, vol. 2, pp. 1–28, 2022, doi: 10.1186/s40066-022-00369-2.

[8] V. M. Anthony and M. Ferroni, “Agricultural biotechnology and smallholder farmers in developing countries,” *Curr. Opin. Biotechnol.*, vol. 23, no. 2, pp. 278–285, 2012, doi: 10.1016/j.copbio.2011.11.020.

[9] H. M. Treasury, “Green biotechnology and climate change. Eur Biol 12.” 2009.

[10] T. Lybbert and D. Sumner, “Agricultural technologies for climate change mitigation and adaptation in developing countries: policy options for innovation and technology diffusion,” 2010.

[11] P. Mäder, A. Fliessbach, D. Dubois, L. Gunst, P. Fried, and U. Niggli, “Soil fertility and biodiversity in organic farming,” *Science (80-. ).*, vol. 296, no. 5573, pp. 1694–1697, 2002.

[12] G. Y. S. Mtui, “Involvement of biotechnology in climate change adaptation and mitigation : Improving agricultural yield and food security,” vol. 2, no. 13, pp. 222–231, 2011, doi: 10.5897/IJBMBRX11.003.

[13] G. Brookes and P. Barfoot, “GM crops: global socio-economic and environmental impacts 1996-2006,” *PG Econ. Ltd, Dorchester, UK*, pp. 1996–2007, 2008.

[14] H. Lu, Y. Liu, H. Zhou, Y. Yang, M. Chen, and B. Liang, “Production of biodiesel from Jatropha curcas L. oil,” *Comput. Chem. Eng.*, vol. 33, no. 5, pp. 1091–1096, 2009.

[15] S. Jain and M. P. Sharma, “Prospects of biodiesel from Jatropha in India: a review,” *Renew. Sustain. Energy Rev.*, vol. 14, no. 2, pp. 763–771, 2010.

[16] D. S. Powlson, A. P. Whitmore, and K. W. T. Goulding, “Soil carbon sequestration to mitigate climate change: A critical re-examination to identify the true and the false,” *Eur. J. Soil Sci.*, vol. 62, no. 1, pp. 42–55, 2011, doi: 10.1111/j.1365-2389.2010.01342.x.

[17] J. M.-F. Johnson, A. J. Franzluebbers, S. L. Weyers, and D. C. Reicosky, “Agricultural opportunities to mitigate greenhouse gas emissions,” *Environ. Pollut.*, vol. 150, no. 1, pp. 107–124, 2007.

[18] G. A. Kleter, C. Harris, G. Stephenson, and J. Unsworth, “Comparison of herbicide regimes and the associated potential environmental effects of glyphosate‐resistant crops versus what they replace in Europe,” *Pest Manag. Sci. Former. Pestic. Sci.*, vol. 64, no. 4, pp. 479–488, 2008.

[19] H. H. Zahran, “Rhizobia from wild legumes: diversity, taxonomy, ecology, nitrogen fixation and biotechnology,” *J. Biotechnol.*, vol. 91, no. 2–3, pp. 143–153, 2001.

[20] Y. Yan *et al.*, “Nitrogen fixation island and rhizosphere competence traits in the genome of root-associated Pseudomonas stutzeri A1501,” *Proc. Natl. Acad. Sci.*, vol. 105, no. 21, pp. 7564–7569, 2008.

[21] L. P. Manavalan, S. K. Guttikonda, L.-S. Phan Tran, and H. T. Nguyen, “Physiological and molecular approaches to improve drought resistance in soybean,” *Plant cell Physiol.*, vol. 50, no. 7, pp. 1260–1276, 2009.

[22] M. P. Apse and E. Blumwald, “Engineering salt tolerance in plants,” *Curr. Opin. Biotechnol.*, vol. 13, no. 2, pp. 146–150, 2002.

[23] D. Zhe and P. D. Mithcell, “Can conventional crop producers also benefit from Bt technology,” *Agric. Appl. Assoc. Ser. Pap.*, no. 103584, 2011.

[24] R. Fawcett, “Consevation Tillage and plant biotechnology-How new technologies can improve the environment by reducing the need to plow,” *http//www. ctic. purdue. edu/*, 2002.

[25] W. Wang, B. Vinocur, and A. Altman, “Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance,” *Planta*, vol. 218, pp. 1–14, 2003.

[26] M. Gomez-Barbero, J. Berbel, and E. Rodriguez-Cerezo, “Bt corn in Spain—the performance of the EU’s first GM crop,” *Nat. Biotechnol.*, vol. 26, no. 4, pp. 384–386, 2008.

[27] G. Barrows, S. Sexton, and D. Zilberman, “Agricultural biotechnology: the promise and prospects of genetically modified crops,” *J. Econ. Perspect.*, vol. 28, no. 1, pp. 99–120, 2014.

[28] B. B. Lin, I. Perfecto, and J. Vandermeer, “Synergies between agricultural intensification and climate change could create surprising vulnerabilities for crops,” *Bioscience*, vol. 58, no. 9, pp. 847–854, 2008.

[29] P. C. K. Cheung and S. T. Chang, “Overview of mushroom cultivation and utilization as functional foods. Cheung PCK (Ed). John Willey & Sons Inc.” 2009.

[30] C. Franche, L. Laplaze, E. Duhoux, and D. Bogusz, “Actinorhizal symbioses: recent advances in plant molecular and genetic transformation studies,” *CRC. Crit. Rev. Plant Sci.*, vol. 17, no. 1, pp. 1–28, 1998.

[31] S. P. Saikia and V. Jain, “Biological nitrogen fixation with non-legumes: An achievable target or a dogma?,” *Curr. Sci.*, pp. 317–322, 2007.

[32] J. R. Welch, J. R. Vincent, M. Auffhammer, P. F. Moya, A. Dobermann, and D. Dawe, “Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures,” *Proc. Natl. Acad. Sci.*, vol. 107, no. 33, pp. 14562–14567, 2010.

[33] S. K. Dhungana, B. Kim, J. Son, H. Kim, and D. Shin, “Comparative study of CaMsrB2 gene containing drought‐tolerant transgenic rice (Oryza sativa L.) and non‐transgenic counterpart,” *J. Agron. Crop Sci.*, vol. 201, no. 1, pp. 10–16, 2015.

[34] A. M. Sevanthi *et al.*, “Integration of dual stress transcriptomes and major QTLs from a pair of genotypes contrasting for drought and chronic nitrogen starvation identifies key stress responsive genes in rice,” *Rice*, vol. 14, no. 1, pp. 1–28, 2021.

[35] S. Dixit, A. Singh, N. Sandhu, A. Bhandari, P. Vikram, and A. Kumar, “Combining drought and submergence tolerance in rice: marker-assisted breeding and QTL combination effects,” *Mol. Breed.*, vol. 37, pp. 1–12, 2017.

[36] D. LI, L. I. U. Hui, Y. YANG, P. ZHEN, and J. LIANG, “Down-regulated expression of RACK1 gene by RNA interference enhances drought tolerance in rice,” *Rice Sci.*, vol. 16, no. 1, pp. 14–20, 2009.

[37] Y. Oladosu *et al.*, “Submergence tolerance in rice: Review of mechanism, breeding and, future prospects,” *Sustainability*, vol. 12, no. 4, p. 1632, 2020.

[38] E. M. Septiningsih *et al.*, “Identifying novel QTLs for submergence tolerance in rice cultivars IR72 and Madabaru,” *Theor. Appl. Genet.*, vol. 124, pp. 867–874, 2012.

[39] B. Wang, Z. Li, Q. Ran, P. Li, Z. Peng, and J. Zhang, “ZmNF-YB16 overexpression improves drought resistance and yield by enhancing photosynthesis and the antioxidant capacity of maize plants,” *Front. Plant Sci.*, vol. 9, p. 709, 2018.

[40] R. Manikandan, S. Sathish, N. Balakrishnan, V. Balasubramani, D. Sudhakar, and V. Udayasuriyan, “Agrobacterium mediated transformation of indica rice with synthetic cry2AX1 gene for resistance against rice leaf folder,” *J Pure Appl Microbiol*, vol. 8, no. 4, pp. 3135–3142, 2014.

[41] M. Li *et al.*, “Reassessment of the four yield-related genes Gn1a, DEP1, GS3, and IPA1 in rice using a CRISPR/Cas9 system,” *Front. Plant Sci.*, vol. 7, p. 377, 2016.

[42] M. Jaidka, S. Bathla, and R. Kaur, “Improved technologies for higher maize production,” in *Maize-production and use*, IntechOpen London, UK, 2019.

[43] B. Sammons\*, J. Whitsel, L. G. Stork, W. Reeves, and M. Horak, “Characterization of drought‐tolerant maize MON 87460 for use in environmental risk assessment,” *Crop Sci.*, vol. 54, no. 2, pp. 719–729, 2014.

[44] S. Mittal *et al.*, “Structural, functional, and evolutionary characterization of major drought transcription factors families in maize,” *Front. Chem.*, vol. 6, p. 177, 2018.

[45] D. E. Nelson *et al.*, “Plant nuclear factor Y (NF-Y) B subunits confer drought tolerance and lead to improved corn yields on water-limited acres,” *Proc. Natl. Acad. Sci.*, vol. 104, no. 42, pp. 16450–16455, 2007.

[46] X. Wang *et al.*, “Bt rice could provide ecological resistance against nontarget planthoppers,” *Plant Biotechnol. J.*, vol. 16, no. 10, pp. 1748–1755, 2018.

[47] A. Mustroph, “Improving flooding tolerance of crop plants,” *Agronomy*, vol. 8, no. 9, p. 160, 2018.

[48] L. Shaffer, “RNA-based pesticides aim to get around resistance problems,” *Proc. Natl. Acad. Sci.*, vol. 117, no. 52, pp. 32823–32826, 2020.

[49] S. Liu, M. Jaouannet, D. A. Dempsey, J. Imani, C. Coustau, and K.-H. Kogel, “RNA-based technologies for insect control in plant production,” *Biotechnol. Adv.*, vol. 39, p. 107463, 2020.

[50] Y. Zhang, K. Massel, I. D. Godwin, and C. Gao, “Applications and potential of genome editing in crop improvement,” *Genome Biol.*, vol. 19, pp. 1–11, 2018.

[51] M. S. Homrich, B. Wiebke-Strohm, R. L. M. Weber, and M. H. Bodanese-Zanettini, “Soybean genetic transformation: a valuable tool for the functional study of genes and the production of agronomically improved plants,” *Genet. Mol. Biol.*, vol. 35, pp. 998–1010, 2012.

[52] A. M. Polizel *et al.*, “Molecular, anatomical and physiological properties of a genetically modified soybean line transformed with rd29A: AtDREB1A for the improvement of drought tolerance.,” 2011.

[53] A. K. Pandey *et al.*, “Functional analysis of the Asian soybean rust resistance pathway mediated by Rpp2,” *Mol. Plant-Microbe Interact.*, vol. 24, no. 2, pp. 194–206, 2011.

[54] G.-H. Lu *et al.*, “Effects of an EPSPS-transgenic soybean line ZUTS31 on root-associated bacterial communities during field growth,” *PLoS One*, vol. 13, no. 2, p. e0192008, 2018.

[55] L. Palma, D. Muñoz, C. Berry, J. Murillo, and P. Caballero, “Bacillus thuringiensis toxins: an overview of their biocidal activity,” *Toxins (Basel).*, vol. 6, no. 12, pp. 3296–3325, 2014.

[56] Y. Bel, J. J. Sheets, S. Y. Tan, K. E. Narva, and B. Escriche, “Toxicity and binding studies of Bacillus thuringiensis Cry1Ac, Cry1F, Cry1C, and Cry2A proteins in the soybean pests Anticarsia gemmatalis and Chrysodeixis (Pseudoplusia) includens,” *Appl. Environ. Microbiol.*, vol. 83, no. 11, pp. e00326-17, 2017.

[57] P. Steduto *et al.*, “Quinoa.” FAO (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS), 2012.

[58] M. N. Ahmad *et al.*, “Effects of soil fluoride pollution on wheat growth and biomass production, leaf injury index, powdery mildew infestation and trace metal uptake,” *Environ. Pollut.*, vol. 298, p. 118820, 2022.

[59] F. Taheripour, T. W. Hertel, B. N. Gopalakrishnan, S. Sahin, and J. J. Escurra, “Agricultural production, irrigation, climate change, and water scarcity in India,” 2015.

[60] A. Pellegrineschi *et al.*, “Stress-induced expression in wheat of the Arabidopsis thaliana DREB1A gene delays water stress symptoms under greenhouse conditions,” *Genome*, vol. 47, no. 3, pp. 493–500, 2004.

[61] J.-K. Zhu, “Plant salt tolerance,” *Trends Plant Sci.*, vol. 6, no. 2, pp. 66–71, 2001.

[62] P. Barfoot, “Global impact of biotech crops: Income and production effects, 1996-2007,” 2009.

[63] X. Duan *et al.*, “Expression of Pinellia pedatisecta lectin gene in transgenic wheat enhances resistance to wheat aphids,” *Molecules*, vol. 23, no. 4, p. 748, 2018.

[64] Y. Zhang *et al.*, “Efficient and transgene-free genome editing in wheat through transient expression of CRISPR/Cas9 DNA or RNA,” *Nat. Commun.*, vol. 7, no. 1, p. 12617, 2016.

[65] D. Cram *et al.*, “WheatCRISPR: a web-based guide RNA design tool for CRISPR/Cas9-mediated genome editing in wheat,” *BMC Plant Biol.*, vol. 19, pp. 1–8, 2019.

[66] J. A. Baum *et al.*, “Control of coleopteran insect pests through RNA interference,” *Nat. Biotechnol.*, vol. 25, no. 11, pp. 1322–1326, 2007.

[67] M. Wiegmann *et al.*, “Barley yield formation under abiotic stress depends on the interplay between flowering time genes and environmental cues,” *Sci. Rep.*, vol. 9, no. 1, p. 6397, 2019.

[68] L. Xiong, “Abscisic acid in plant response and adaptation to drought and salt stress,” *Adv. Mol. Breed. Towar. drought salt Toler. Crop.*, pp. 193–221, 2007.

[69] T. X. Nguyen and M. Sticklen, “Barley HVA1 gene confers drought and salt tolerance in transgenic maize (Zea mays L.),” *Adv Crop Sci Tech*, vol. 1, no. 105, p. 2, 2013.

[70] F. Gürel, Z. N. Öztürk, C. Uçarlı, and D. Rosellini, “Barley genes as tools to confer abiotic stress tolerance in crops,” *Front. Plant Sci.*, vol. 7, p. 1137, 2016.

[71] X. Zeng *et al.*, “Origin and evolution of qingke barley in Tibet,” *Nat. Commun.*, vol. 9, no. 1, p. 5433, 2018.

[72] M. Galli *et al.*, “CRISPR/Sp Cas9‐mediated double knockout of barley Microrchidia MORC1 and MORC6a reveals their strong involvement in plant immunity, transcriptional gene silencing and plant growth,” *Plant Biotechnol. J.*, vol. 20, no. 1, pp. 89–102, 2022.

[73] M. Thudi *et al.*, “Genomic resources in plant breeding for sustainable agriculture,” *J. Plant Physiol.*, vol. 257, p. 153351, 2021.

[74] H. C. P. Singh, N. K. S. Rao, K. S. Shivashankar, and J. Sharma, *Climate-resilient horticulture: adaptation and mitigation strategies*. Springer, 2013.

[75] D. Perovic, D. Kopahnke, A. Habekuss, F. Ordon, and A. Serfling, “Marker-based harnessing of genetic diversity to improve resistance of barley to fungal and viral diseases,” in *Applications of genetic and genomic research in cereals*, Elsevier, 2019, pp. 137–164.

[76] D. L. Singha, N. Tuteja, D. Boro, G. N. Hazarika, and S. Singh, “Heterologous expression of PDH47 confers drought tolerance in indica rice,” *Plant Cell, Tissue Organ Cult.*, vol. 130, pp. 577–589, 2017.

[77] P. Paul *et al.*, “MADS78 and MADS79 are essential regulators of early seed development in rice,” *Plant Physiol.*, vol. 182, no. 2, pp. 933–948, 2020.

[78] N. Cui *et al.*, “Runoff loss of nitrogen and phosphorus from a rice paddy field in the east of China: Effects of long-term chemical N fertilizer and organic manure applications,” *Glob. Ecol. Conserv.*, vol. 22, p. e01011, 2020.

[79] F. J. Perlak, R. L. Fuchs, D. A. Dean, S. L. McPherson, and D. A. Fischhoff, “Modification of the coding sequence enhances plant expression of insect control protein genes.,” *Proc. Natl. Acad. Sci.*, vol. 88, no. 8, pp. 3324–3328, 1991.

[80] J. Shi *et al.*, “ARGOS 8 variants generated by CRISPR‐Cas9 improve maize grain yield under field drought stress conditions,” *Plant Biotechnol. J.*, vol. 15, no. 2, pp. 207–216, 2017.

[81] J. Li, J. Hu, L. Xiao, Q. Gan, and Y. Wang, “Physiological effects and fluorescence labeling of magnetic iron oxide nanoparticles on citrus (Citrus reticulata) seedlings,” *Water, Air, Soil Pollut.*, vol. 228, pp. 1–9, 2017.

[82] A. Visioni, A. Al-Abdallat, J. A. Elenien, R. P. S. Verma, S. Gyawali, and M. Baum, “Genomics and molecular breeding for improving tolerance to abiotic stress in barley (Hordeum vulgare L.),” *Genomics Assist. Breed. Crop. Abiotic Stress Toler. Vol. II*, pp. 49–68, 2019.

[83] J. A. Heinemann and U. N. C. on T. and D. (UNCTAD), “Commentary VI: Genetic engineering and biotechnology for food security and for climate change mitigation and adaptation: Potential and risks.,” in *United Nations Conference on Trade and Development (UNCTAD), Wake Up Before it is Too Late: Make Agriculture Truly Sustainable Now for Food Security in a Changing Climate. Trade and Development Review*, 2013, pp. 203–218.

[84] J. Chikaire, F. N. Nnadi, N. Ejiogu-Okereke, and J. A. Echetama, “Agricultural biotechnology and bio-safety: tools for attaining food security and sustainable industrial growth in Nigeria,” *Cont. J. Agric. Sci.*, vol. 6, no. 1, 2012.

[85] D. J. Spielman, “Pro-poor agricultural biotechnology: Can the international research system deliver the goods?,” *Food Policy*, vol. 32, no. 2, pp. 189–204, 2007.

[86] W. Quaye, R. M. Yawson, E. S. Ayeh, and I. Yawson, “Climate change and food security: The role of biotechnology,” *African J. Food, Agric. Nutr. Dev.*, vol. 12, no. 5, pp. 6354–6364, 2012.

[87] M. B. H. Najafi and B. H. Lee, “Biotechnology and its impact on food security and safety,” *Curr Nutr Food Sci*, vol. 10, no. 2, pp. 94–99, 2014.

[88] M. Godliving YS, “Involvement of biotechnology in climate change adaptation and mitigation: Improving agricultural yield and food security,” *Int. J. Biotechnol. Mol. Biol. Res.*, vol. 2, no. 13, 2011.

[89] J. Abah, M. N. Ishaq, and A. C. Wada, “The role of biotechnology in ensuring food security and sustainable agriculture,” *African J. Biotechnol.*, vol. 9, no. 52, pp. 8896–8900, 2010.