MODERN BIOTECHNOLOGY FOR CLIMATE CHANGE ADAPTION OF CROPS

Abstract

Climate change is caused by the long-term release of greenhouse gases over the years negatively affecting the environment and decreasing agricultural production and productivity. The major causes of climate change include the emission of carbon dioxide and other greenhouse gases from human interventions, animal husbandry, and the primary burning of crop residues in agriculture. Biotechnology can positively reduce the effects of climate change through modern biotechnology. Therefore, climate change is a very serious problem in global warming of the earth which is prioritized to be focused on the development of agriculture. In this chapter, crop adaptation to climate change through biotechnology, biotechnology for environmental stress adaptation, and biotech crops related to climate change are focused. Conventional biotechnology approaches such as reduced use of artificial fertilizer, energy-efficient farming, plant tissue culture, and traditional breeding methods for varieties that are adaptable are examples of possible solutions that might help mitigate the detrimental effects of climate change. Through modern biotechnology approaches to climate, ready crops are developed which is resistant to various environmental stresses. Both the traditional and advanced biotechnology approaches will play a very crucial role in the present and future global climate change adaption of crops.

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

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I. INTRODUCTION

Climate change is the long-term, average change or fluctuation in its attributes described by the Intergovernmental Panel on Climate Change (IPCC). “Climate change” is described as long-term (more than 30 years) substantial changes in climate conditions [1]. According to the IPCC report, two ways cause climate change one is anthropogenic which includes changes in land use by human activities and another one is natural forces like volcanic eruption, solar cycle emphasis, and continental shift [2]. Climate change is caused by two major factors: changes in the earth’s circular orbit, gases within the environment, and manmade consequences. Different types of atmospheric gases have the property to absorb the portion of the solar energy reflected by the earth’s surface. These gases include greenhouse gases (GHGs) which restrict radiation from reaching space and induce warming in the atmosphere. Industrial development and other activities include carbon dioxide, methane, hydrofluorocarbons (HFCs), nitrous oxide, sulphur hexafluoride (SF6), and perfluorocarbons (PFCs) is cause the greenhouse gas emission [3]. The climate changed as a result of rising CO2 levels, which is frequently ignored in enrichment studies and could result in pest and disease assaults [4]. Agriculture comes under the climate-based economy with regional features, as agriculture relies on the selection of crops suited to a region’s environment. The Food and Agriculture Organization (FAO) states that if the current crop prospects and food conditions remain the same then the current GHG emission and climate change trends continue, the frequency of extreme weather conditions will rise. This will result in an increase in the incidence of pests and pathogens, abiotic stress, and decreased crop productivity in many important 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 quicker and more accurate methods used to develop genetically modified (GM) crops through genetic engineering techniques [6]. Plant breeding and crop improvement have been revolutionized through recent techniques of genetic engineering. Various techniques are utilized to develop high-yielding, better-suited agricultural varieties that are resistant to changing climate, including genome editing, next-generation sequencing techniques, and genomic-assisted breeding. [7].

Climate change may be mitigated by, among other things, utilizing fossil fuels, reforestation, and lowering greenhouse gas emissions [2]. The world population is increasing 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 decrease the emission of greenhouse gases and creation of biotic and abiotic stress-resistant crops [3].

II. AGRICULTURAL BIOTECHNOLOGY

Fermentation methods, plant tissue culture, mutation, and recombinant DNA technology, genomic research, marker-assisted breeding, and transgenic technologies 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 virus-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 plant species where the gene of interest and marker for the particular agronomic performance are already known. Marker-assisted breeding is a modern method used in the transfer of a particular gene from the donor into the different recipient crops. Examples include introducing bacterial blight resistance within the rice family, increasing higher beta carotene levels in rice for instance, banana, and cassava, *fusarium* wilt resistance in chickpea, and rice with submergence tolerance. Recombinant DNA technology is used in the modern biotechnology tool of genetic engineering. It involves the cutting of DNA and vector molecules at a specific location with the help of specific restriction enzymes inserting it into the suitable host and modifying DNA molecules containing one or more genes of interest. Transgenic can be created by modifying particular genes and transferring the modified genes into the animals. Recombinant DNA technology and transgenic techniques have significant advantages because through these techniques genes from different sources may be modified and transferred into different organisms and plants to develop resistance to biotic stresses like insects and pests, herbicides resistance, and various abiotic stress resistance like temperature, humidity, drought, salinity. The use of agricultural biotechnology in underdeveloped nations is difficult in relation to climate change and food safety.

III. CROP ADAPTATION TO CLIMATE CHANGE THROUGH BIOTECHNOLOGY

1. **Green House Gas Reduction:** The 25 % greenhouse gases (carbon dioxide, methane, and nitrous oxide) emission into the environment is caused by different agricultural practices such as excess use of fertilizers, production of rice, overgrazing, and deforestation. Through carbon sequestration, energy-efficient farming, and a decrease in the use of synthetic fertilizers, biotechnology is one of the possible route to combat climate change [9].

2. **Environmentally Friendly Fuels Use:** Agricultural techniques play a major role in overcoming the negative impact on agricultural production and the surrounding environment. The transport sector produces CO_2 and we can overcome this CO_2 emission through the production of biofuels, from conventional crops like Jatropha and genetically engineered crops such as sugarcane, oilseed, and rapeseed [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].

3. **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 CO_2 emissions into the environment. Modern Biotechnology such as genetically modified

organisms and other related technologies facilitates fewer fuel consumption by decreasing the necessity and frequency of spraying and reducing ploughing. Genetically modified cotton, soybean, brinjal, and canola reduce fuel consumption and CO_2 production by reducing insecticide application is the best example [12]. In a year 2005 the application of biotechnology decreases fuel usage amounted to savings of about 962 million kg of CO2 emission, and a reduction of 40.43 kg/ha or 89.44 kg/ha CO_2 emission while the adoption of reduced tillage or no tillage practices due to less fuel consumption respectively [13].

4. **Energy-Efficient Farming Use:** Green biotechnology has been utilized to help eradicate world hunger by employing several technologies that allow the generation of more fruitful plants resistant to both biotic and abiotic stress. This technology allows the use of less environmentally friendly energy and fertilizer and the practice of soil carbon sequestration. The production of biofuels from both non GM and GM crops such as mustard, sugarcane, 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, became 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 CO_2 emissions [14], [15].

5. **Carbon sequestration:** Carbon sequestration is the capture or uptake of carbon-containing substances like carbon dioxide (CO_2). Carbon sequestration describes any increase in soil organic carbon content caused by 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 combat the increasing CO_2 concentration in the atmosphere. Enhancement of carbon sequestration is possible by reducing the traditional tillage operation. Agriculture residue leaves at least 30% on the land surface; agriculture reduces loss of the CO_2 concentration from agriculture and it plays a very important role in reducing water through evaporation, increasing soil stability, and creating the cooler soil microclimate. Different soil conservation methods help to reduce soil erosion, and may also sequester soil carbon and enhance methane (CH_4) 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 led to the sequestration of 63,859 million tons of CO_2 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 method improves soil fertility and stores more CO_2 in the soil, which helps to mitigate climate change [13].

6. **Reduced artificial fertilizer:** Artificial fertilizers contain harmful toxic compounds and they are used in agriculture but they contaminate the environment. When artificial fertilizers interact with common soil bacteria, they contribute to the creation of different greenhouse gases (N_2O) from the soil into the surrounding environment. Different artificial fertilizers like ammonium sulphate, ammonium chloride, ammonium phosphates, sodium nitrate, and calcium nitrate are the major chemical constituents that are responsible for the formation and release of different greenhouse gases into the

surrounding environment [13]. The negative effects of artificial fertilizers can be reduced by using eco-friendly biotechnology-based fertilizers.

7. **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]. The cultivation of GM crops is another possible solution for fulfilling the nitrogen requirements in the soil because genetically modified crops use nitrogen more efficiently as compared to non-GM crops. The nitrogen-efficient GM canola is the best example of a GM crop because this reduces the amount of artificial fertilizer that is lost into the environment or mixed into the soil and water sources and it also impacts positively farmers' income through improved profitability [9]. Soil nitrogen management that matches crop demands can minimize N_2O emissions and avoid negative effects on the quality of water. Manipulation of animal feed and waste management can also help to minimize CH_4 and N_2O emissions from animal husbandry [17].

IV. BIOTECHNOLOGY FOR ENVIRONMENTAL STRESS ADAPTATION

Climate change decreases agriculture production due to insufficient rainfall, and the potential weed emergence, diseases and pests caused by bacteria, viruses, and fungi (Table 1). Agricultural biotechnologies are one of the important conceivable strategies to respond to such a worldwide challenge that prevent the negative consequences of such changes by offering new options for developing stress tolerance [21].

Table 1: Traditional biotechnology techniques for mitigating climate change

Measure	Biotechnology	Application	Reference
Climate change mitigation: Reduced use of artificial fertilizer	No-till farming Agroforestry	Banana, Coffee, Horticultural farming Mycorrhizal, and actinorhizal symbiosis	[16]
Carbon capture and storage	Production of biofuels	Bioethanol derived from sugarcane Jatropha and palm oil biodiesel	[10]
Respond to changing climate: Biotic and abiotic stress adaptation	Culture of tissues Agroforestry	Sorghum, millet, and sunflower tolerant to drought Coffee and banana farm shading	[22]

Table 2: Adaptation and mitigation of climate change using modern biotechnology

Measure	Biotechnology	Application	Reference
Decreased fuel usage	Engineer reduces resistance to herbicide, reduces spray	GM soybean, GM canola	[18]
	Engineer insect protection, reduce spray	Cotton, GM maize, and brinjal	[23]
Reduced use of fertilizer	Nitrogen fixation by genetic engineering	Rhizobium genetic improvement; Non-legume nitrogen fixation reduction	[20]
Carbon sequestration	To present, no farming has occurred as a result of improvements in biotechnology, green energy, and nitrogen-efficient GM crops	Herbicide-resistant soybeans, N-efficient GM canola, GM energy crop	[10], [17], [18], [24]
Climate change adaptation	Molecular markers help with stress resistance through marker-assisted breeding	Maize, and wheat resistant to drought	[25]
Biotic and abiotic stress adaptation	Engineering tolerance to drought, salt, and heat	GM tomato, rice	[21]
Increased production per unit land area	Agricultural output is increased per unit area of land	Fungi, bacteria, and viruses resistant GM cassava, GM maize, GM canola banana, and potato	[26]

1. **Adaptation to Biotic Stresses :** Genetically engineered crops that have been developed which is resistant to different biotic stresses like insect, bacteria, viruses, and fungi that could reduce the crop yield has been developed. In modern biotechnology, a soil bacterium (bacillus thuringiensis, Bt) gene is transferred to different crops like corn, cotton, soybean, and canola, and it provides insect, and pest resistance like 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 major role in pest control. Roundup-ready soybean, corn, and canola have been developed through the introduction of herbicide-resistance genes. Biotic stress-resistant crops such as potatoes, cassava, and other crops are also being developed and commercialized through genetic engineering [27].

2. **Adaptation to Abiotic Stresses:** Agricultural production and climate are forced by various environmental stresses like salt, drought, severe temperature, and oxidative stress. Conventional breeding approaches along with plant biotechnological methods are essential approaches for crops for resistance to abiotic stresses. These approaches include

the selection of drought-resistant crops and cultivation, which allow them to flourish under tough climatic circumstances on marginal soils [3].

3. **Agro-ecology and Agroforestry:** Agriculture is affected in many tropical locations by the effect of global warming, which is altering temperature and precipitation patterns. The effect of severe temperature and rainfall, decreasing many rural farmers' ecological and economic vulnerability and strengthening agroecological resilience to severe weather conditions is mitigated by shade management in crop systems [28]. Environmental problems and restoration of degraded ecosystem is solved through the use of fungal application in biotechnology is called mycobiotechnology. Mycoforestry and mycorestoration are emerging fields of study research and implementation for the restoration of the damaged ecosystem of forests [29]. The atmospheric nitrogen can be fixed symbiotically by fibrous plants like casuarinas (Casuartna sp.) and alders (Alnus sp.) and this phenomenon is beneficial to forestry and agroforestry [30]. Endo- and ectomycorrhizal symbiotic fungi, as well as actinomycetes, are being employed as forest regeneration inoculants [31].

V. BIOTIC CROPS ADAPTED TO CLIMATE CHANGE

1. **Rice:** Rice is the major cereal crop used in the research work, and this is the major staple food crop in most of the developing countries. Research based on 227 adequately watered fields predicted a significant negative impact on rice output owing to projected warmer temperatures [32]. As a result, attempts have been made to produce climate-ready traits of rice crops, resulting in improved performance under various stress conditions [7].

   Transgenic rice has been developed for resistance to drought and the genes are expressed at the growth and reproductive stages of the plants which is drought tolerance i.e. Capsicum annum methionine sulfoxide reductase [33], and it is one of the important findings in the rice. If the plants are under abiotic stresses like chilling, drought, and salinity they accumulate several toxic aldehydes [34]. When the plant is in stressful conditions methylglyoxal known as cytotoxic metabolites has been accumulated. It has been discovered that preventing methylglyoxal buildup is a potential strategy for increasing resistance to stress in plant, such as rice adaptation to lower temperature, salinity fluctuations, heavy metals, drought, and submerged conditions. As a result, genetic modification of the glyoxylate pathway has been utilized successfully in rice to make it resistant to a variety of biotic and abiotic challenges [35]. RNAi is a promising approach to silence the expression of particular gene. In rice, the RACK1 gene is inhibited, and the involvement of this gene in drought responses was discovered [36].

   Due to the global warming, flooding becomes more frequent and intense and it is critical to produce food grains like rice, wheat, and maize that can endure waterlogging and prolonged submergence. In the rice variety IR72 three non-SUB1 QTLs have been discovered, and these QTLs suggested that the ethylene-dependent mechanism of the SUB-1 gene may exist [37]. On a rice chromosome 1 a SalTol QTL have been identified which is resistant to salinity stress, and various salt-tolerant varieties have been published, including BR23, BRRI dhan40, BRRI dhan41, BRRI dhan53, and BRRI dhan 54 [38]. In terms of biotic stressor tolerance, many countries have created genetically modified rice lines that contain the Bt gene from Bacillus thuringiensis [39]. In rice plants, chimeric expression of the Bt genes cry2Aa and cry2Ac was found to be useful against rice leaf folders [40]. The genes gna1a, dep1, and gs3 were discovered to be important in the production of climate-ready rice using CRISPR-mediated silencing [41].

2. **Maize:** Maize, the second most important cereal crop in around 125 under developed countries, produced around 1161.86 million metric tonnes globally between 2022-23 (USDA) [42]. The reduction of its growth and yield due to drought conditions and drought stress alone has been reported up to 37% yield loss. The genetically modified maize i.e. "MON87460" was developed through transgenic technologies and this is widespread resistance to drought. This transgenic maize expresses the cold shock protein B under water stress conditions, to preserve cellular processes, and this includes the RNA stability and translation [43]. In 2013 the hybrid maize i.e., "DroughtGardTM" was created and released for cultivation in the United States to conserve water for cultivation by slowing leaf growth, particularly during the important flowering periods [44]. In dry circumstances, the modified maize showed reduced wilting and maintained photosynthesis, with a 50% increase in grain production [45]. Drought-responsive transcription factors discovered as crucial in maize drought tolerance include *AP2*, *bZIP*, *NAC*, *HD-Zip*, and *MYB* [46]. Flooding or waterlogged conditions in maize are another likely effect of climate change, to which most cereal crops are especially vulnerable. Maize is more vulnerable to flooding as compared to other crops, and several QTL-related research is being conducted in maize to discover the resistance genes [47]. Using RNAi technology, the putative V-ATPaseA coding region from western maize rootworm (war) was exploited to develop insect-resistant maize. 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].

3. **Soybean:** Soybean is one of the most significant crops that may be utilized to provide sustenance for both humans and animals. Soybean is an excellent source of industrial oil and has been one of the primary focuses in crop development programs [50]. Therefore, the production and seed quality of soybean is affected by the different biotic and abiotic stresses [51]. Drought, among the several abiotic stressors, leads to a 40% decrease in plant growth and development [21]. The drought-prone soybean variety BR16 was transformed with the AtDREB1A gene from Arabidopsis thaliana's drought-inducible promoter rd29A. Drought tolerance in soybeans is improved by increasing the rate of photosynthesis, 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 Agrobacterium spp. strain CP4 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) gene renders RR crops resistant to the herbicide glyphosate [54]. [55], According to a 2014 study cry1Ab gene expression has a crucial function in the suppression of larval feeding and proliferation of Anticarsica gemmatalis. Several investigations have shown that the synthetic cry1Ac gene causes complete larval mortality in Anticarsia gemmatalis while decreasing larval survival in Pseudoplusia and Helicoverpa zea [56].

4. **Wheat:** Wheat is another major cereal crop that contribute to world food security and is the primary source of food for more than half of the world's population. Wheat 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 climate change and accompanying water constraints is decreasing by up to 2 million people [58]. Seed germination is affected by increased temperature and increases the risk of failure. The activation and control of certain stress-related genes is the foundation of abiotic stress tolerance molecular regulatory systems. Because the metabolism and signaling of growth regulators such as abscisic acid and gibberellic acid can be regarded as a tipping point in terms of wheat seed germination, understanding the temperature-dependent molecular processes that may alter seed germination is critical [59]. Furthermore, transcription factors are being studied to improve agricultural water stress. One of them, the dehydration-responsive element binding (DREB) gene, was biolistically inserted into bread wheat and placed under the control of a stress-inducible promoter from the *rd29A* gene [60]. [61], In terms of plant resistance to salt stress conditions, salt-tolerant plants often handle additional abiotic stressors such as cold, freezing heat, and drought, and such high-performing genetically modified wheat plants have been created globally. SNPs in 37 quantitative trait loci connected to salt tolerance characteristics were discovered during the assessment and identification of QTLs in 150 winter wheat cultivars. These have been useful in improving wheat, and it is anticipated that found polymorphism will be exploited in the next breeding programs [62]. Aphid resistance is improved by manipulating the transgenic Pinellia pedatisecta agglutinin (PPA), using genome editing techniques like TALEN, and CRISPR. Wheat powdery mildew resistance is improved by manipulating the target gene TaMLO [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].

5. **Barley:** Following rice, maize, and wheat, barley is regarded as the world's fourth most important cereal crop. Among these, barley is highlighted as a crop that can respond to abiotic difficulties in a relatively short period [66]. Because of barley's inherent stress tolerance, researchers are becoming increasingly interested in finding stress-sensitive genes using small/large-scale omics studies, comparative genomics, and genetic transformation to overexpress some of these genes [67]. Abscisic acid is known to be involved in a variety of metabolic activities that help plants cope with drought, salt, and cold [68]. The *H.* Vulgare abundant protein 1 (*HVA1*) has been reported to be activated by ABA and various abiotic stimuli, and overexpression of HVA1 in different cereal plants has been demonstrated to promote tolerance to various abiotic stressors [69]. Several such pathways underpinning stress-related genetic variation have been examined and found to have a considerable impact on barley output improvement when climatic conditions vary [70]. Several barley species have been sequenced and mapped, with Tibetan hulless barley being recognized as a resource for expanding barley genomics research [71]. *MORC1*, a defense-related gene, has been identified in Arabidopsis thaliana and has been used to increase resistance to both Blumeria graminis f. sp. Hordei, the cause of barley powdery mildew, and Fusarium graminearum in barley as the genes responsible for several abiotic stress resistance in the genome of wild species of barley (*AWCS276*) paving the pathway to several improvements in a barley crop [72]. The identification of significant QTLs is another fundamental challenge in crop development. Exome-QTL sequencing was utilized to efficiently map the black lemma and pericarp

(Blp) loci, as well as the QTLs important for resistance to net blotch disease (caused by the fungus Pyrenophora teres) [73]. Several abiotic stress tolerance traits, including drought tolerance, submergence tolerance (*SUB1*), and salinity tolerance controlled by QTLs [74]. It has been shown that CRISPR/Cas9-mediated mutation reduces callose deposition in sieve tubes, making plants resistant to aphid infestations. Molecular markers for important resistance genes and quantitative trait loci (QTL) against rust (Puccinia spp.) and powdery mildew (Blumeria graminis f. sp. Hordei), Rhynchosporium commune have been identified in barley[75]. The use of developed markers in marker-assisted selection on barley has been considered limited in recent years. However, high-throughput Phenotyping approaches, in conjunction with NGS, are thought to improve the capacity to uncover loci associated with a variety of key features [7].

Table 3: Climate-resilient crops developed through modern biotechnology

Crop	Gene and modern biotechnology methods used	Target traits	Trait improvement	References
Rice	Methionine sulfoxide reductase B2 (*CaMsrB2*) gene from capsicum annum expressing transgenic rice	Drought resistance	At the reproductive stage drought resistance	[33]
Rice	Gene expression of *RACK1* silenced by RNAi	Drought resistance	Increased growth despite water stress	[36]
ASD India Rice	Transgenic gene DNA helicase-47 (PDH47) from Pisum sativum	Drought resistance	Several stress-responsive genes regulated	[76]
Rice	MADS-box transcription factor edited by CRISPR for *MADS78* and *MADS79* gene	Seed germination	Cellularization of the endosperm and early seed development	[77]
Rice	Gene *gna1a*, *dep1*, and *gs3* knockdown	Climate-resilient crop for abiotic stress resistance	Large grain size and quantity, increased grain weight, and high yield	[41]
Rice	CRISPR editing at the 3 terminus of the *OsLOGL5* coding sequence	Drought resistance	Grain yield increase	[41]
Rice	Homeostasis of Cytokinin	Stress resistance	Grain yield increase	[78]
Rice	CRISPR editing of the *gs3* and *dep1* genes	Salinity tolerance		[41]
Rice	ERF transcription factor gene *OsERF922y* silenced by CRISPR editing	Disease resistance	Rice blast resistance in both the seedling and	[79]

			tillering stages	
Maize	RNA stability and translation of Cold shock protein B preserved in transgenic maize	Drought resistance	Maintain cellular activities in the face of water stress	[43]
Maize	Transgenic maize with homologous *ZmNF-YB2*	Drought resistance	Grain yield has grown by 50 %	[45]
Maize	CRISPR/Cas9 system to edit *ARGOS8*	Drought resistance	Plant yield has increased	[80]
Maize	Thermo-sensitive male sterile5 gene i.e. TMS5 knocked out using the ZFN method	Heat resistance	Male-sterile maize crops that are temperature-dependent	[81]
Maize	RNA interference in the coding region of putative V-ATPase	Pest resistance	Western corn rootworm resistance	[48]
Soybean	Arabidopsis gene *Δ1-pyrroline-5-carboxylate synthase* (*P5CR*) overexpression	Resistance to drought	Tolerance to high-temperature conditions	[41]
Soybean	Transformed with the *AtDREB1A* gene under the control of rd29A	Drought resistance	Increased plant photosynthetic rate, chlorophyll content, and stomatal conductance	[52]
Soybean	Virus-induced *WRKY* transcription factor gene silencing	Stress resistance	Biotic and abiotic resistance	[53]
Soybean	The *car1-2* transgene from Arabidopsis thaliana	Herbicide resistance	Chemical class imidazolinone resistance	[55]
Soybean	Transgenic using *cry1Ab* gene from *Bt*	Pest resistance	*Anticarsia remmatalis* larval feeding and growth resistance	[55]
Wheat	*DREB* (dehydration-responsive element binding) gene	Water stress	Resistance to water stress conditions	[60]
Wheat	*Pinellia pedatisecta agglutinin* (*PPA*) transgenic with transgene modification	Pest resistance	Aphid injury resistance	[63]
Wheat	*TaMLO* target gene TALEN and CRISPR-mediated genome editing	Pest resistance	Powdery mildew disease resistance	[63]
Wheat	*EDR1* gene editing with CRISPR/Cas9	Pest resistance	Powdery mildew disease resistance	[46]
Wheat	*TaGASR7* gene for length	Drought	The length and	[65]

	and weight of grain editing using CRISPR	resistance	weight of the grain have been increased	
Barley	Stress-responsive transcription factor *HvSNAC1* overexpression	Drought resistance	Allow for dryness without reducing crop productivity	[82]
Barley	*MORC-1* gene editing using CRISPR/Cas9	Pest resistance	*Blumeria graminis f. sp. Hordei* and *Fusarium graminearum* resistance	[72]

VI. MODERN BIOTECHNOLOGY BIOSAFETY POLICIES FOR CLIMATE CHANGE AND FOOD SECURITY

The advancement of contemporary biotechnology in response to climate change crop adaptability is dependent on national biosafety policies. Several nations have now ratified the Cartagena Protocol on bio-safety for the application of modern biotechnology in crops and climate change mitigation [83]. Bio-security and bio-safety systems are critical to maximizing biotechnology's benefits in terms of environmental and health issues handled through scientific risk assessment [84]. For the crops to be released into the environment safely, biosafety rules must be implemented.

Public-private collaborations must be considered for the successful application of modern biotechnology to mitigate climate change and improve 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. GHG emissions may be decreased by enacting sound agricultural development policies and employing agricultural biotechnology to combat climate change. This should be done by biosafety rules to guarantee that no harm to humans or 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.

GM foods are safe, according to the industrial perspective. Biotechnology and genetic engineering, when used correctly. Will increase human health and welfare while saving time and money. In terms of climate change and health care, a proper risk assessment process should be utilized on GM crops, employing well-authenticated and up-to-date chemical analytical methodologies to estimate the contents of its main and minor components and compare their levels to those of the matching parent line [87].

VII. 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 taken 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 risks 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 human knowledge limits, the possibility of undiscovered risks cannot be ruled out with perfect certainty, neither for genetically modified or transgenic crops nor for any other strategy such as conventional breeding and natural selection [89].

VIII. CONCLUSION

In recent years, the safe advancement and application of modern biotechnology have contributed to crop adaptation to climate change through reduced greenhouse gas emission, use of bioethanol or biodiesel, lower fuel consumption, energy-efficient farming, carbon sequestration, reduced use of artificial fertilizers, and increased use of biofertilizers. These are several potential options for increasing agricultural output and food security while simultaneously safeguarding our environment from the harmful consequences of climate change. Modern biotechnology has the potential to significantly increase agricultural output and food security while also safeguarding our biological ecology from the detrimental impacts of climate change. Some cereal crop examples are examined in this chapter in their evolution, demonstrating how these methods using current biotechnology may be applied more efficiently to boost agricultural production. Modern biotechnology has been used to design climate-ready crops.

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.

