

Review Article

Climate Change and Mitigation: Discussion of Climate-Smart Agronomical and Breeding Tools in view of the Global Food Security Dynamics

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Abstract

Agriculture which feeds the world over population is the sector being predominantly affected by the global climatic variations. In this scenario, the main aim of all the mitigation and adaptation strategies is only to combat all the detrimental effects which are posed by the environmental changes, and then finally sustain the proper development after reversing these harmful impacts. This review represents an overall analysis of the climate change and its general impacts onto the crop yield variability along with their due mitigation strategies especially those of for the agriculture sector, generally by focusing on the interdisciplinary collaborations among the Plant Scientists to mitigate the climate changes.

Keywords: Agronomy; Climate Change; Food Security; Mitigation Strategies; Plant Breeding

Introduction

Climate change is mainly referred as the persistent increase in the

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levels of greenhouse gases including all the fluorinated gases like CO₂, CH₄ and N₂O which lead to drastic changes in the temperature, rainfall patterns and ultimately cause undesirable effects on the land and water resources, droughts and floods [1,2]. Agriculture is the sector which is predominantly affected by the global challenges which the mankind is facing now like the food security, environmental degradation, economic developments and the climate changes.

No other goal is the most benevolent and important then the feeding of this ever-growing population which will expand over nine billion by 2050. Notwithstanding the fact that the rates of worldwide crop production are distantly less than the amounts of crops that are required to meet the estimated demand of the population by 2050 [3,4]. As the population is growing with rapid pace, along with the uplifted standards of the living, the utilization of the natural resource commodities is also increasing, ultimately leading to an amplified pressure on the Agriculture sector to intensify and expand at the same growing pace. Besides this, Agriculture sector is the key emitter of the Greenhouse gases into the atmosphere.

Now, the main aim of all the mitigation and adaptation strategies is only to combat the negative effects posed by the climate change [5], and to reverse its effects and then finally sustain the development in this scenario. Therefore, the advantages of all the mitigation exercises will be evident for the next several decades in the coming future as well [6].

Hence, one of the most effective and efficient way to enhance crop production and to attain stability in this regard, is to develop improved varieties through plant breeding. This is practised throughout the world and has demonstrated very positive results over the centuries. From simple selection to the complex molecular and omics strategies [7], the glorious journey of the Plant Breeding has now enabled us to develop some new and improved cultivated varieties that can excellently cope with the changing climatic conditions.

To increase the world food production on the urgent basis, the social, environmental and economic challenges of the global agriculture are needed to be addressed thoroughly [8]. Some of the factors which directly contribute to boost up the agricultural productions are: the more upgraded agronomic practices, use of superior cultivars [9] along with the improved farming systems [10] and their components. So, the approaches of Agronomy, Breeding and the Farming System have clear and discrete effects on the outputs of the Agriculture. In this scenario, the collaboration between the Agronomy and Breeding has been widely recognized [11,12].

This review represents an overall analysis of the climate change and its general impacts on the crop yield variability along with their mitigation strategies [13] especially those of for the agriculture sector, which directly deals with the food security regimes and certain environmental factors throughout the globe. Now, the present-day cutting-edge technologies like integrated agronomical outputs, certain genomic approaches, and biotechnology combining with the use of climate-smart breeding tools are highlighted in this review, for devising an inter join strategy to mitigate the effects of certain climatic variations critically those onto the agricultural productions.

Analysis of Crop Yield Variability under Climate Change Impacts

Atmospheric Carbon Dioxide (CO₂) which is a well-known greenhouse gas triggers changes in the climate leading to alter its temperature, rainfall, sea level and soil moisture [2,14]. Such climatic variations effect agriculture, ecological systems, economy and the human health. While the climate changes affecting agriculture in terms of adverse crop growth and production should also be given the due attention [15-17]. Fluctuations in the crop yield are mainly determined by the yearly changes occurring in the climatic conditions. Different livestock and crop products are mainly influenced by the available water and the climatic conditions.

Agriculture production is adversely affected by the varying climatic conditions, such as increase in the mean temperatures for crop growth and the enhanced magnitude and frequency of harsh weather events [18,19]. Additionally, it overwhelms the farmer who finds it difficult to adjust to the revamping climatic conditions as the sowing time and the other cultural operations for a crop are influenced by the time and amount of the rainfall. Moreover, temperature changes also affect the duration of the crop growing season along with its rate of evapotranspiration. Hence, it's necessary to conform the agricultural production designs to fit in the shifting climatic conditions.

These alterations in the climate can boost up the water usage meanwhile dropping-off the water availability which is elementary for the industry, urban population, and natural ecosystems and for the other users [20]. So, now agriculture will try out for the sparse water availability with the other users. Studies had shown the use of either regression techniques or simulation models for calculating the environmental changing effects on a crop's productivity. In this regard, studies which used the simulation models are McCarthy et al. [21], Holzworth et al. [22] and Basso et al. [23]. While Mendelsohn et al. [24,25], Tannura et al. [26] and Martinez et al. [27] studies showed the application of regression models to forecast the changes in yield of the especial crops owing to the diverse climatic conditions by operating a documented data of the climate and yield [28-33].

So, changes in the climatic conditions effecting mean yield of the crops are highlighted in the former studies. Yet, the effects of climate variability on the crop yield fluctuations are very less studied [34,35]. Hence, small amount of objective data is accessible as how crop yield varies against the refashioning climatic conditions. Now, helpful data regarding the influence of climatic variables like rainfall and temperature on the varying crop yield could be obtained by using econometric models that use recorded climatic and crop yield data [36]. This data also helps to develop realistic simulation models to calculate climate change impacts on the agricultural productions.

It's interesting to analyses the impacts of the policies to mitigate climate change onto the agriculture because of the heavy expenses which are related to the increasing energy prices and the greenhouse effects [24]. Farmers can possibly enjoy handsome opportunities to get preservation payments for the productions which will limit the release of gases from the greenhouse. So, it's significant to check the climate change implications for the crop yield variability's. By using documented data of the climatic conditions and crop yields, functions of stochastic productions are evaluated for quantifying the effects of climate changes onto variance and mean for the sugar beet, potato, barley and wheat yields. The evaluated production functions exhibit

either that the climatic variables boost, or they diminish the variance of the yields [36].

Agricultural Adaption's to the Climate Change

Throughout the globe, major usage of the land comes from the Agriculture sector. Nearly, 1.2-1.5 billion hectares of the land is currently under the cultivated crops, while 3.5 billion lands are under the grazing systems. Besides this, about 4 billion hectares of the land which is continuously declining, falls under the forests as forestry is also one of the major areas which are affected by the climate change [37]. This land under forests is also used by the humans for different kind of activities, and not only this land but some global fisheries are also intensively used even beyond to their capacities by the humans. To reach the demand of food per capita, and to fulfill the requirements of this rapidly growing population estimated to 9 billion in the coming future, sustainable increases in the production of agriculture sector should have to hold on [38] and it must reach up to 70%, which means ultimately doubling of the prevalent food production by 2050 [39]. Moreover, Agriculture sector is a significant social, cultural and economic activity, and it also furnishes the broad extents of the ecosystem services. More importantly, this sector in several of its forms plus locations is highly vulnerable to the climatic variations. Therefore, it is the need of the hour to evaluate and identify vital options to adapt Agriculture to this climate change in the coming years. The term of 'adaption' is used to inculcates all the proceedings of adjustment practices, processes and capital increases in reaction to the hazard of the climate change [5], moreover the reactions in decision environment, like changes in institutional or social structures or some transformed technical alternatives influencing the capacity or potential for these deeds are needed to be discovered. Hence, there is a significantly strong need to focus on the adaptation of agriculture to the climate change. Several considerations for this need are the followings:

- The emission of greenhouse gases in the past has already contributed to the 0.1 °C warming of the temperature every year for some decades and the prediction exists that the mean temperatures will increase from 2.6 to 4 °C before the end of this 21st century [40-42] so, mandatory adaptation strategies are already inevitable.
- Especially from the last three decades, there are certain climate change influences which are occurring more promptly [2] than their former ratios are likely tube considered [40]. If these drifts continued to be like this, then ultimately more accelerated and proactive adaptations will become the necessity.
- Climate change scenario has a high end which is rapidly increasing with the passing of time [2,40], moreover, these high temperatures could have potentially non-linear and progressively adverse influences on the prevailing agricultural events
- Climate changes could also offer chances for the agricultural investments, which will reward the early action takers for investing in these possibilities [43,44].

Hence, there is a huge variation of the agricultural attributes owing to the diverse range of the climate and other environmental modifications; economics, cultural and institutional factors along with their interactions. This indicates that there is a widespread array of possible options for the adaptation. Some of the possible adaptation options presented by the Agronomists in the scenario of heat and drought stress are shown in figure 1.

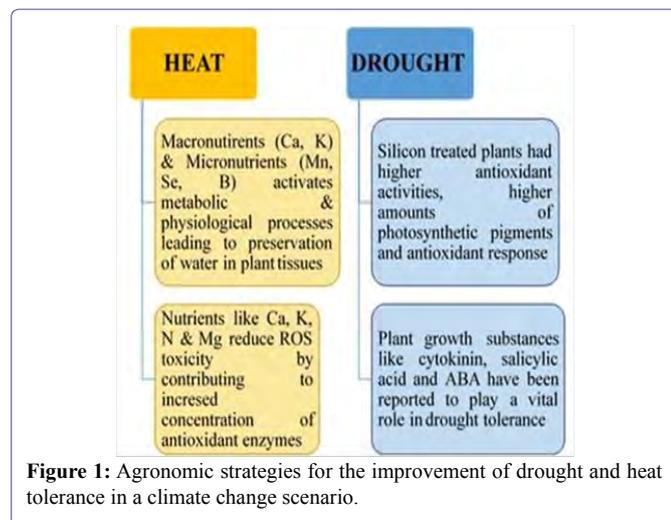


Figure 1: Agronomic strategies for the improvement of drought and heat tolerance in a climate change scenario.

Local and Global Mitigation Strategies to Protect Agriculture Sector from the Impacts of Climate Change: 2000-2080

The impacts and variability of the climate change on agriculture are considered world widely. Firstly, food security which is a prominent part of the ecosystem and human activities is now under the threat of hazardous anthropogenic impediments on the climate of the earth [45-50]. Secondly, each country considers now the possible benefits and damages of the impacts of climate change over the next few decades on its territory, and internationally also because they will influence the use of the resource, trading patterns, welfare of the people, and the regional planning along with the local as well as the global policies.

Recent researches indicate that the crops showed positive responses to the increased CO₂ levels if the climate change was absent there [19,51-53]. While, the high frequency of the floods and drought type extreme events, combining with the impacts associated with the shifted rainfall patterns and elevated temperatures, will collectively check the yields and contribute towards the production risks in many areas of the world [20,54]. Now, the under developed nations are more exposed to the climate change as compared to the developed nations because of; the agriculture sector which shows more dominance in their economies, their hot climates at the baseline, the lack of the capital for their adaptive actions, and their intensified openness to the extreme events [1]. Hence, climate change can cause severe impacts on the under developed countries which currently have almost 800 million undernourished people.

Certain correlated factors which determine the food demand and its distribution in the world being the key players are; the land resources, agro-climatic conditions, and their regulations [55]. But all these factors including insurance of the global food security regimes are highly affected by the specific social and economic pressures, accessibility to the food, available technology and advancements, and the prevailing and estimated trends in the population expansion [56]. Globally, the per capita take of the calories has been increased to 2800 from 2400 calories in the last three decades. The main causes behind this change are the enhanced production systems, globalization of the food markets and the international trade. Now, it's very clear

that to minimize the undesirable effects of the climate change on the ecosystems and humans, some adaptation measures along with the mitigation strategies are the prerequisite (Figure 2) [13,57]. Some of the mitigation strategies in this regard are presented in figure 3.

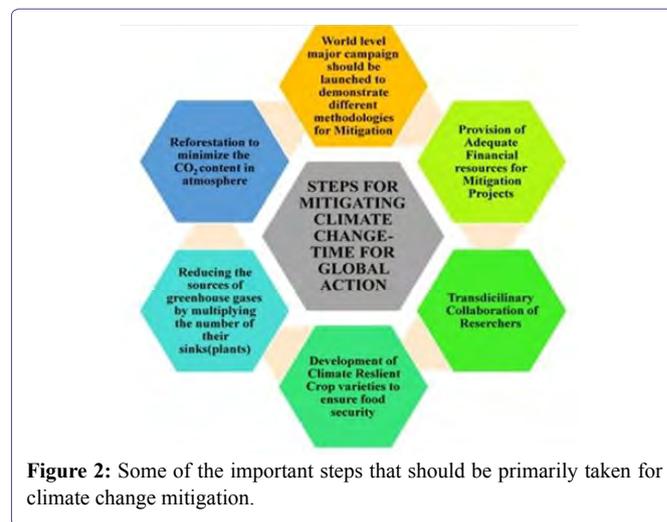


Figure 2: Some of the important steps that should be primarily taken for climate change mitigation.

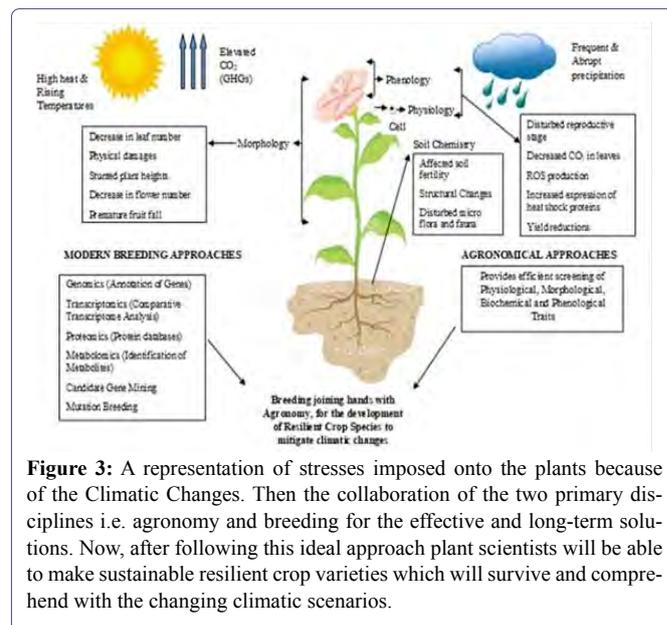


Figure 3: A representation of stresses imposed onto the plants because of the Climatic Changes. Then the collaboration of the two primary disciplines i.e. agronomy and breeding for the effective and long-term solutions. Now, after following this ideal approach plant scientists will be able to make sustainable resilient crop varieties which will survive and comprehend with the changing climatic scenarios.

Role of Agronomy in addressing the climate change and food security dynamics

The world over climate changes along with the other important local and global environmental variations, are partly related to the human involvement into the food productions, food dispense and then its usage. These environmental variations involve those occurring in the soil, land covers, in biodiversity, nitrogen and carbon cycling, and in the freshwater supplies [58]. Meanwhile, climatic variations can also prove to be fruitful for some of the areas, particularly which are situated at 55° above Northern latitudes. But for the under developed world, overall changes including the ones which are particularly

related to the climate, can cause complexity in reaching the food security. This is because of the commonly forecasted detrimental impacts on the agriculture sector particularly in the sub-tropical and tropical countries [59-63].

Now, here are the three important reasons for this: firstly, the developing world is mainly vulnerable to the remarkable changes which are occurring in the rainfall and temperature patterns. For example, Southern Africa region could be drier and warmer according to the climate assessments [1,64]. Moreover, a rise between 0.9 and 3.5 °C in temperature is estimated in the coming decades [65] and a raising fluctuation in rainfall is predicted which shows the regions will become drier specifically those in the east [66]. Rather, the intensity and frequency of the utmost events like floods and droughts is also predicted to be increased [41,67]. Secondly, under developed economies those are highly dependent on their ecosystems and agriculture, which showed geographical openness and elevated poverty ranks, are specifically vulnerable to the immediate influences of the climate changes [61,68]. Thirdly, as agriculture is the primary food source for the numerous people living in the developing world, the negative effects on the crop production will then affect the overall local food supply for them. Meanwhile, world population will climb up to ca. 9 billion from the today's ca. 6 billion people by 2050 and to supplement these expected antagonistic effects of the climatic variations onto the crop production, the global food demand is expected to be high [19]. Though it's hard to anticipate the future's food production, but it is evident that overall 50% increase in the crop production is needed now over the few coming decades to encounter this due high demand [69,70]. So, now, the matter of concern is that the environment would be further deteriorated if the conventional crop practices and technologies are kept used to meet this increasing food demand [3,4,71]. For instance, the increasing fertilizer applications will cause high emissions of the greenhouse gases which will ultimately aggravate the climate change. While in return, further food production will be undermined by these changes.

Agronomy is now facing the two main challenges like the assistance in devising such systems for the food production and to co-ordinate more efficiently with the other disciplines. Some of the Agronomic researches proving useful in this scenario are shown in table 1.

Genomics and Breeding Strategies for the Increase of Crop Yield in Climate Change Scenario under the Drought Stress

Today, we are facing a difficult challenge of feeding the world's ten billion population by 2050 while simultaneously minimizing the adverse effects of the environment onto the food production. Agriculture sector is contributing 30% in the emission of greenhouse gases

through anthropogenic causes [76-78]. Therefore, some mitigation strategies should be adopted to control this emission of greenhouse gases from the agriculture. While, drought is one of the serious aftermaths of the climatic variations and ultimately will risk the food security of millions of people around the globe [31,79,80].

The production of cereals is being affected by the different biotic and a biotic stresses which are emerged because of the climate changes. The most noticeable stresses are the biotic ones. Plants fix CO₂ to form carbohydrates via the process of Photosynthesis and this occurs through C3 or C4 carbon fixation mechanisms. It had been noted that the C4 plants less responded towards the elevated contents of CO₂ [81,82]. The main cause of the drought are the elevated temperatures, which ultimately disturb the plant's photosynthetic rates leading to the reduction in crop yield.

Hence, drought is emerging as a critical problem because of the changing climate. The trait controlling the drought tolerance is found to have a complex nature as it is being controlled by the numerous genes with the trivial effects [83,84]. So, for the genetic remedial of the drought tolerance, the functional biology accompanying the genomics could be regarded as the good strategies. Therefore, to understand this drought response phenomenon within the plants, an understanding regarding the plant's physiology and its genetic bases is mandatory to develop. In this scenario a strong collaboration among various disciplines are necessities to overcome this hurdle of Climate Change and attain our desired goals regarding crop yields as shown in figure 3.

Biotechnological Approaches for Climate Change Adaptation and Mitigation

The most extreme threats to the agriculture in the coming future are the consequences of the climate changes. The most visible effects of the changing climate will be on the amounts of precipitation, insects and pests, temperature, pathogens and on the quality of the water and the soil. Agricultural operations contribute 25% approximately in the emission of greenhouse gases, and besides this the agricultural activities emit 48% methane (CH₄) and 52% nitrous oxide (N₂O) in the fields of Rice [85]. Greenhouse gases contribute in warming the environment through both anthropogenic and natural ways by averting the radiations which try to reflect into the atmosphere [50]. Different gases like Carbon dioxide (CO₂), Nitrous oxide (N₂O), Methane (CH₄), Sulphur hexa-oxide (SF₆) and Hydro fluorocarbons (HFCs) are mainly released by the industries. Globally, the concentration of these emitted gases is increasing gradually in the atmosphere which is contributing towards the climate change. Humans can mitigate the climatic variations by reducing the sources of greenhouse gases meanwhile multiplying the number of their sinks (plants).

Research	Benefits	Drawbacks	Reference
Extensification	Increases agricultural production and area for the crop production	It is restricted by the accessibility to the new landmass, plus side by side increase of the greenhouse gases along with the several harmful environmental effects	Nkamleu and Manyong, [72]
Intensification	New cultivar is introduced along with the large increase in the extent of the mechanization and more utilization of the pesticides, fertilisers, herbicides and the irrigations.	It has been noted that it triggers some consequential negative feedback processes in the environment. For instance, elevated adoption of the rice-wheat system is occurred due to the high usage of the fertilizers, irrigations, diesel and the electricity. Such practices have direct influences on the release of greenhouse gases.	Aggarwal et al.,; Garnett et al.,; Rockström et al., [73-75]

Table 1: Agronomic Research to encounter deleterious climatic feedbacks.

This can be achieved through reforestation to minimize the CO₂ content present in atmosphere and by focusing on the utilization of the renewable energy instead of the biomass [86].

Now, the production in Agricultural sector is mandatory to meet the demands of the ever-increasing population. Agricultural biotechnology focuses on the use of several biological organisms as well as their sub-cellular constituents in the various fields of the agriculture. The methods which are employed in agriculture till date are mainly the tissue culture, marker assisted selection, genetic engineering and the conventional breeding. Hence, Biotechnology can be a guaranteed tool to mitigate the harmful impacts of the climatic variations by reducing the amounts of greenhouse gases [87] including the minimum fertilizer applications [88] along with the bio-fuel consumptions. It also includes the biotic stresses [89], resistance to biotic and the carbon sequestration [90].

Climate-Smart Breeding of Plants under Digital and Biotechnological Revolution

Climate change accompanying global warming, uncertain weather changes, and increased events of the weeds, pathogens and pests, is significantly affecting the important cropping systems. In this demanding situation, several strategies are required to enhance our genetic achievements with the aim to develop innovative varieties. The main reliance of our breeding for the next generation is onto the large data management tools, huge plant breeding populations, proficient high-throughput technologies, and on the downstream molecular and biotechnological techniques as shown in table 2.

Conclusion/Future Prospects

Climate change is so far, a serious threat for mankind due to its wide implications on the human health, environmental safety and especially agriculture that cause an ultimate threat to world food

security. Agriculture is now facing a new challenge to meet the increasing global food demands under the severe threats of climate change. In this regard FAO prepared a white paper which highlighted the idea of climate-smart agriculture to tackle the food security dynamics under the impacts of climate change. Moreover, under developed countries are in need to enhance their cultivated crop area additional to 120 million ha to feed their over whelmed population [19]. Hence, modern agricultural tools like genomics, gene mining and biotechnology should be applied to increase the global anticipated crop production demands.

Therefore, some integrated and interdisciplinary approaches will be required to adapt to these climatic variations (Figure 2) [103]. As the evident and increasing impacts of the climate changes are not seemed to reverse the effects now, some strict actions are timely needed to be taken to avert their undesirable and unpredictable results. In this regard, modern and conventional biotechnology approaches should be incorporated into the national policies to make domestic crop varieties more resilient against the changing environmental scenarios. Globally, the current atmosphere strongly demands for the advanced setups to regularize the ambient and optimistic collaborations among the Plant Scientists to articulate the climate change mitigations, especially within the circles of agriculture. Now, the genuine decision making, and implementation is required to find meaningful centralized solutions against this common cause; naming “climate change”.

Author Contributions

SS came with idea and wrote the manuscript while ZHS and critically reviewed and proofread the manuscript.

Conflict of Interest

All authors declare no conflict of interest.

Tools	Application	Outcomes	References
Genetic Resources	Provides enhanced understanding of adaptive mechanisms against climate change, knowledge of genetic backgrounds & phenotypic plasticity of different crops.	Association mapping populations are being made which represent a valuable source of natural genetic variations.	Sacco et al.,; Gao et al.,; Taranto et al., [91-93]
QTL Mapping and Marker Assisted Selection	Identification of elite DNA molecular markers, having correlation with given traits in segregating populations.	Allows the emplacement of QTLs in linkage groups, which are beneficial in breeding programs. Numerous methods for QTL analysis have been developed so far.	Sehgal et al., [94]
Genome Wide Association Study	The underlying genetic mechanism of resilience and resistance traits effective for climate change, their predictive and causative factors have been known.	Climate resilient crops has been made in cereals and legumes.	Dawson et al., 2015; Mousavi-Derazmahalleh et al., [95,96]
Mutation Breeding	Chemically induced mutagenesis & DNA screening techniques resulted Targeting Induced Local Lesions in Genomes (TILLING)	Effective tool for the discovery of allelic variants which are responsible for crop adaptation under abiotic and biotic stresses because of climate change.	Kurowska et al.,; Jankowicz-Cieslak and Till, [97,98]
Genome editing	It allows gene transfer, directed mutagenesis and control over gene expression.	In soybean drought and salt tolerance by disrupting the Drb2b and Drb2a genes have been achieved and have also been recently reported in cocoa	Cardi et al.,; Curtin et al.,; Farrell et al., [99-101]
Bioinformatics and Data Mining	An Efficient Tool for researchers and breeders to analyse and interpret their own data, hence training and empowerment skills in bioinformatics tool is needed.	Through the combination of expertise in different areas like wet-lab techniques, field trials, data analysis and interpretation more potential in successful development of climate resilient crops.	Brazas et al., [102]

Table 2: The Breeder’s tools for combating the challenges of climate change.

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