Review Article

Impact of climate change on crop adaptation: current challenges and future perspectives

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Abstract

Climate change (i.e. changes in rainfall pattern and temperature) is a global issue affecting all regions and almost all sectors of life. This paper reviews the impact of climate change on crop adaptation and highlighted the recent advances used against these abiotic stresses. Reports have predicted agriculture is most vulnerable sector to climate change. The increasing climate variability has serious threats to crop adaptability and availability. Thus, climate change has threatened the food security. Therefore coping strategies to mitigate the threats to food security are matter of urgency. This can help to mitigate the impact of climate change on crop adaptation. The feasible adaptation practices that could be adapted include sowing time adjustments, stress tolerant varieties and short duration cultivar. The government and policymakers should support sustainable agriculture, farming practices and new technologies. The use of new genetic engineered methods can help to produce more transgenic plants against these environmental extremes.

Keywords: Abiotic Stress; Climate Change; Crop Adaptation; Novel Practices; Transgenic Plants

Introduction

Fluctuations in temperature and rainfall pattern are evident in many regions around the globe. Scientific research provides evidence of increase in temperature from 2-4.5 °C during 21st century. During last three decades temperature has been increased at the surface of the earth than earlier decades since 1850. The period from 19th century to 21st century is probably the warmest era of the last fourteen centuries due to solar radiations (IPCC-2014). Uncertain and uneven distribution of rainfall not only creates a

flooding devastation but also become cause of longer dry spells and eventually drought conditions [1].

Climate change is a serious issue all over the world; it has not only affected plants but has impacts on almost all areas of life (animal, fishes and human being, etc.). Research showed that developed countries have more severe (8-11 %) threats due to climate change than developing countries [2]. Natural disasters in North America, Central America, and the Caribbean revealed vulnerabilities of farming community to extreme weathers.

Agriculture is severally affected in these regions by drought, floods, hurricanes, freezes, and other forms of climatic changes [3]. Climate change in Pakistan is affecting the economy of country; more adversely affected sector is agriculture. Under rainfed agriculture, temperature and rainfall are serious threats to crop adaptation. Northern and Southern regions of Khyber Pakhtunkhwa (KP) have serious threat to crop production and livelihood [1]. It has both positive and negative impacts on crops productivity i.e., crop yield in some regions increased and in other regions decreased it depends on irrigation and cropping areas. Only temperature is not affecting crop adaptation but it has also been observed that in some areas crop adaptation is more threatened due to the change in precipitation [4]. In many disciplines, there is a gap between research and implementation, research-practice, and science-policy gap, causing serious threats to food security. Another problem is uncertainties and not knowing about the future climates. The major challenge now a day is reduction of the food security threats from climate change [5].

This paper focuses on impact of climate change on crop adaptation. The next sections provide an overview of the climate variability, causes of climate change, stresses produced due to climate change, impacts on agricultural crops, strategies to cope with climate change, its impact on some important major crops of Pakistan, and some recent genetic engineered approaches.

Climate variability and causes of climate change

The considerable climate variability (computation of means and variability of related parameters of variables e.g., temperature, rainfall and the wind over some periods of time) has been widely studied. It is estimated that due to increase in temperature, climate variability is increasing. Climate variability receives significant impacts on

plants physiology in many ways. Precipitation has increased in high latitudes, while decreased in most of the tropical and subtropical regions. Climate variability and extreme weather conditions increase multiple stresses not only for crop plants but also for animals [6].

Since the past few years the impacts of climate change and particularly its biological effects have been so obvious. There is an increased emission of gases for instance carbon dioxide, methane, nitrous oxide and Halo-Carbons due to human activities and natural sources these gases absorb solar radiations and causes greenhouse effect [7]. Atmospheric CO₂ has been significantly increased to the level of 388 ppm due to human activities [8]. High temperatures, low rainfall, salt stress and high intensity of light causing drought [9].

Stresses produced due to climate changes and its impacts on crops adaptation

The effects of abiotic stresses on crop adaptation and production have been observed due to fluctuation in climatic conditions [10]. Plants abiotic stresses are produced due to abiotic factors. These factors include extreme levels of temperature (heat or cold stress), light, radiations, water (flooding and drought stress), chemicals (metals and pH), and gaseous contaminants (ozone, sulfur dioxide). Heat and drought are frequently occurring stresses under field conditions, have a substantial impact on the performance of plants and their offspring's and can permanently plague plants [11].

Plants production depends upon range of temperature around the plants of each species; because plants require optimum range of temperature for their production and adaptation. Impact on plant phenology due to change in temperature are equally significant [12]. Heat stress reduces grain yield and grain-filling period, frost causes sterility and abortion of grains [13] and drought stress

adversely affects the physiology, morphology and biology of plants [9]. Although in some areas of the world located within the northern widths above 55 °C climate changes will have positive effects on agricultural production but many plants especially native to warm habitat suffer from negative impacts of these changes. Extreme events takes place during the summer season are serious threats for crop adaptation and production for instance wheat plant reduces its period of planting to flowering and emergence to flowering due to rise in temperature, evaporation and transpiration. Rise in 1 °C of temperature leads to a reduction of 5 days flowering. Period of grain filling is also effected due to rise in temperature eventually leads to biomass reduction [7].

For example, after wheat rice is the second major staple food crop and is economically important crop for Pakistan. Production of rice was increased 4.33 % with 3 °C increase in temperature. However, 5.71 % and 15.26 %, reduction in crop production was observed due to increase in precipitation (during September-October) by 5% and 15% respectively [14].

The impact of climate change on production of four major food crops (e.g., wheat, rice, maize and sugarcane) in Punjab, Pakistan studied revealed that extreme climatic conditions (temperature, precipitation) are threatening the production of major crops of Pakistan. Effects of Increased temperature are more damaging for crops production than precipitation [15]. Ali *et al.* [16] studied the impacts of climate change on four major crops of Pakistan presented in (Table 1).

Table 1. Impacts of climate change on four major crops of Pakistan during 2014-15 Ali *et al.* [16]

Crop	Importance	Impact on Crop Productivity
Wheat	Largest Staple food crop of Pakistan	1.9 % percent reduction in productivity
Rice	Second major food crop and economically most important item for Pakistan	3 % increase in rice growth (due to increase in precipitation)
Maize	Important livestock feed and used industrially for starch and oil	5 % reduction in productivity
Sugarcane	Cash crop gained US\$171.8million of foreign exchange	8 % reduction in productivity

Impact on plants morpho-biochemical and physiological processes

Due to rapid changes in climatic conditions, plants are facing novel ecological circumstances that are outside the optimum range to adaptation. Plant migration may not be a solution with the unusual changes in temperature and rain fall pattern. Even though plants have manipulated their physiology that is advantageous in novel environments, but climate change may be as dangerous as to drive plants beyond the tolerance ranges [17]. The abiotic stresses seriously affect morpho-biochemical process of many plant species [18]. However for

predicted climatic situations for the coming few years, the responses of crops physiology propose that they will grow faster, with slight changes in flowering and fruiting, depending on the crop variety and specie [19].

The best temperature range for plants is 10-35 °C. Increase in temperature up to a certain level will enable plants to produce more energy but beyond these limits the photosynthesis of the leaves sharply decreases and is irreversibly lost [20]. Drought decreases the turgor pressure of plants which ultimately limits cell growth. Water deficiency influences the activity of photosynthetic enzymes and reduces the

efficiency of metabolic processes and consequently dysfunctions the photosynthetic apparatus [21]. Increase in concentration of CO₂ due to changing climatic conditions results in declined plant respiration and increased temperature. Crop respiration increases with increase in temperature up to the range of 15-40 °C and then decline [8]. The high temperature for long time period affects the morphological traits of rice and *Brassica* genotypes [22, 23]. Rubisco enzyme involved in the process of carbon fixation, by which photosynthetic organisms convert atmospheric carbon dioxide to energy-rich molecules. At normal temperature ranges Rubisco activase keeps Rubisco active by eliminating metabolites. A slight increase in temperatures causes Rubisco deactivation due to the production of inhibitory compounds (xylulose-1, 5-bisphosphate). Above optimum range of species temperature, Rubisco activase also denatures and insoluble aggregates are formed that are unable to remove inhibitors and to activate Rubisco. In cotton very rapid reduction in the activation state of Rubisco has been observed due to elevation of temperature [24].

Reactive oxygen species (ROS) comprising of hydrogen peroxide (H₂O₂), super oxides (O₂), hydroxyl ions (OH) and singlet oxygen (O₂) are by-products of biological metabolisms, and are controlled by enzymatic and non-enzymatic antioxidant defense systems. Under normal environmental conditions, ROS are primarily produced at a low concentration in cells and organelles but their concentration increased in stress conditions [25]. Excessive production of ROS in plants is very reactive and dangerous to proteins, lipids, and DNA which eventually damages cell and causes cellular death [26]. The high salt concentration increase the proline content and decrease the relative water content of *B. rapa* genotypes [27].

Strategies to cope with this climate change

Changing climatic conditions have impact on food security from the local to global level. Climate change threatening the food security which is not a new issue. However, previously no attention was paid to mitigate this issue. But now climate change adaptation strategies are a matter of urgency. For adaptation of crop in changing climatic conditions following strategies are needed.

Cultural practices

A few studies conducted to understand the farmer's managing strategies to mitigate climate hazards for crop adaptation. The coping strategies of farmers in eastern Uttar Pradesh, India that mitigate or minimize stressful events (temperature and rainfall) include change in timing of sowing and harvesting, use of short duration cultivar, inter cropping, change in cropping pattern, use of ground water for irrigation and agroforestry. All these practices are useful to reduce the effects of climate change on crop adaptation [28].

Some adaptation practices such as sowing time adjustments, adopted drought tolerant varieties, and shifted to new crops are very useful for crop adaptation in four provinces (98 % of country's land area) of Pakistan. 8-13 % higher food security level and reduced exposure to weather risks are observed by adapting these practices at farm level [29]. Application of nitrogen fertilizer is very important mitigation option and helps in adaptation of plants to global warming. It is an indirect energy source and is important to maintain soil fertility and to increase crop adaptability and yield. Thus, the role of fertilizer in feeding the world is incontrovertible [30].

Conventional methods

Plant breeding plays vital role in crop improvement strategies for both abiotic and biotic stresses. It provides solutions for food security under unfavorable climatic conditions and to avoid stresses during

critical periods of crop life cycles through creation of varieties with different duration and stress tolerant. Combination of participatory and evolutionary plant breeding is the major breeding strategy to cope with the risks of climate change [31].

The use of genetic diversity for evaluation, selection, recombination and inbreeding to achieve crop cultivar improvement is among the major factors determining success in plant breeding. Landraces are major sources of genetic diversity such as wheat landrace collections stored in gene banks contain wider genetic diversity and useful source of stress tolerance and includes varieties adaptable to different environmental conditions [32].

Non-conventional methods

Marker assisted selection

Marker-assisted selection plays vital role in improvement of quantitative traits for speeding up the breeding process. Developments in crop genomics are sources of useful information to identify DNA markers, which are useful for marker-assisted breeding programs. Genomics along with bioinformatics and metabolomics resources are globally important for crop improvement [33]. For heat tolerance in bread wheat, three major genomic regions on chromosome 2B, 7B and 7D has been identified. The World Vegetable Center (AVRDC) has also used genetic markers for disease-resistant breeding program in tomatoes. Disease resistant tomato varieties are now available for farmers [34].

Genetic engineered approaches

The genetic modification through Biotechnology is a powerful strategy. Promising material is identified from genetic resources that can be used directly in plant breeding to adapt them in abiotic stresses (heat, drought and salinity, etc.). The expressions of stress-induced transcription factors are tools for improvement of stress tolerance in plants. It can regulate the

expressions of downstream genes linked to abiotic stress responses in transgenic plants [35]. Several transgenic plants have been developed by different researchers against abiotic stresses. These transgenic plants show tolerance to the environmental extremes as compared to non-transgenic plants [36-39].

CRISPR (clustered, regularly interspaced, short palindromic repeat)/Cas (CRISPR-associated protein) is an array of repeat and spacer sequences that work with help of a protein (Cas9). The CRISPR/Cas-9 system provides immunity to bacteria and archaea against the invading genome [40]. Advanced bioinformatics tools and a large number of Cas9 variants will enable researchers to design gRNA/Cas9 tools requiring longer PAM, which will increase its specificity and reduce off-target effects. The CRISPR/Cas-9 is a user-friendly system for the production of non-transgenic plants with counteracts harmful effects from climate change and ensures future food security of increasing population in tropical countries [41]. Recently this efficient genome editing tool has been successfully used in plants against both biotic and abiotic stresses [42]. Kim *et al.* [43] used this system to enhance abiotic stress tolerance by disruption of *TaDREB2* and *TaERF3*. Recently, Ou *et al.* [44] upregulated 21 *KUP* genes in cassava after exposure to several abiotic stresses including salt, osmosis, cold, drought, and H₂O₂. However CRISPR/Cas9 technology is not significantly used for further genetic modification in several important tropical plants against both biotic and abiotic stresses, for yield and quality improvements [41].

Conclusion

High temperature and rainfall irregularities are a key indicator of climate change. The Whole world is going to be effected by climatic changes. Arid areas are more vulnerable to increasing temperature and drought stress. Climate changes causing both positive and negative impacts on crops but

negative impacts are more common than positive impacts. Disequilibrium taking place in agricultural productions cannot be eliminated easily. How many efforts and time it would take to eliminate this issue is not clear. Therefore emphasizing is given to manage agricultural productions in the drought and high temperature. Dissemination of new cultural techniques, adapted cropping patterns and conventional and non-conventional methods for improvement of crop varieties would be the suitable derivatives of fundamental change required in the agriculture sector. New crops with increased heat and drought tolerance will help to reduce potential risks. Awareness is necessary for a significant response, which ultimately depends on knowledge and experience. Agriculture extension services, sending farmers' climate information and bringing farmers together in forming communication are important for increasing crops adaptation to climate change. Policies for increasing farmer flexibility would also allow farmers to manage modern climatic conditions. However, we need to develop more stable genetic engineered crops in near future through novel CRISPR/Cas9 methods against environmental extremes.

Authors' contributions

Wrote the manuscript: M Afzal, M Ilyas, G Shabbir, SSA Jan & SA Jan, proofreading, editing and formatting: M Ilyas, SA Jan, SSA Jan & M Afzal.

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