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REVIEW ARTICLE

PLANT BREEDING APPROACHES FOR COMBATING IMPACT OF CLIMATE CHANGE IN AGRICULTURE PRODUCTION: A REVIEW

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ABSTRACT

Climate change is the most pressing environmental challenge of this century creating deleterious impact on the agricultural productivity. Besides all the knock-on effects of climate change, rising concentration of carbon dioxide and temperature affects overall plant physiology, growth, reproduction and resilience. The forth coming generations of crops are most vulnerable to the changing climate which will rely on genetic interventions by the selection of target traits in controlled environments, and high throughput phenotyping and genotyping. Plant breeding approaches plays predominant role to create cultivars which are well adapted to new climate demand, introduce new desirable genes adapted to genetic background as well as broaden genetic traits/genes in a breeding material in pace with environmental change and stress. Genetic breeding techniques gives an ever more cost-effective option to characterize available genetic diversity and also makes the mechanism of climate adaptation and application in crop breeding more acceptable. This paper reviews the impacts of Climate Change on Agriculture sector and also highlights the adaptation of plant breeding technology to reduce and tackle the climate change. The objective is to discuss the evidences of climate change and its impact in food production system. The motive is to prompt the policymaker, breeders and development agents the essentiality of tackling this serious threat so to reduce crop losses related to climate change.

KEYWORDS

climate change, agriculture crop, gene, MAS, QTLs.

1. INTRODUCTION

Climate change is one of the biggest issues the world is facing and is one of the most defining concerns of today's world and has greatly reshaped in the process of altering earth's ecosystem (Arora, 2019). According to The International Panels on Climate Change (IPCC) and the United Nations Framework on Climate Change (UNFCCC), climate change has been identified as greatest threat and pressing environmental challenges of the century (Onoja and Enete, 2011). Climate change is the study of how weather patterns change over decades or longer and the change in climate can take place due to natural and human influences (Brath et al., 2015). Natural and anthropogenic activities of humans like emission of GHGs, aerosols, deforestation, alter land use pattern has resulted in a change in the climatic pattern over time commonly said as climate change (IPCC, 2007). Natural causes include variation in solar radiation, variations in the earth's orbit, mountain building, continental drift and changes in naturally emitted greenhouse gas concentration while artificial causes include emission of carbon dioxide from the combustion of fossil fuels which deplete the ozone layer, leading to global warming (Kakaki, 2013).

The effects of climate change comprise natural disasters, increased average annual temperature, unsteady food production, extreme variation in temperature, drought, health crisis, loss of biodiversity (Kakaki, 2013). Not only global warming, climate change has caused water shortage, flood, drought, change in plant phenology, declined coral reefs, increased coastal erosion and decrease in yield of crops (IPCC, 2014). Further IPCC has estimated, by 2050 the groundwater recharge will decrease to less than

50% of the 1990s value, global warming range will be 1.5°C to 2.3 °C above the 1850-1900 period and the concentration of CO₂ in atmosphere will reach to 500µatm from 280 µatm. And Agriculture is deemed to be an economic activity that is expected to be vulnerable to climatic variability, since it is highly dependent upon weather and climate in order to produce food and fiber (Yohannes, 2016). Rapid population growth and increasing demand than supply of food may increase the number of hunger worldwide but even if the demand matches the supply sudden environmental and climate change may reversely affect the food production system and hence increasing count of hungers (Lenaerts et al., 2019).

Figure 1: Allelic changes are present within networks.

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Allelic changes do not occur independently of other changes; combinations of alleles within gene networks may be required to produce adaptive phenotypes. These networks are affected by environmental and maternal inputs, and in turn influence protein and metabolic networks, although there are feedback loops and multiple points of environmental inputs. Selection acting on phenotypes therefore often influences allele frequencies at a specific gene (red arrow) only indirectly (Franks and Hoffmann, 2012).

Figure 2: Climate change impact on the agricultural sector (Shankar & Shikha, 2017).

2. RELATION OF CLIMATE CHANGE AND PLANT BREEDING

Global Biodiversity and ecosystem are significantly affected by climate change. Many researches had shown the strong ecological and genetic effect of climate change on most organisms and the influences on the physiology, behavior, abundance and distribution of many taxonomic groups, species and ecosystems (Franks and Hoffmann, 2012; Williams et al., 2008). Organisms may perceive the change of climatic condition in two ways; they may either take opportunity of favorable climatic condition to expand distribution or extinction due to stressful condition (i.e. either directly or through matching cues to new condition) (Franks and Hoffmann, 2012). One of the best option for adaptation of plant to climate change and modified environment is development of new genotype and genetic improvement (Henry, 2020). Besides enhancing yield and product quality, genetic have great role in climate change mitigation and reduce environmental stresses in agriculture (Abberton, n.d.).

Plant breeding helps the producers to tackle the challenges through development of new varieties with improved genetic pattern. The ability of crop to mature and set grain within growing season depends on the crop phenology and changes in day length and temperature response to match phenology help the crop to adopt in the given environment (Atlin et al., 2017; Kumudini et al., 2014). Plant breeding rely on selection of target plant for yield and adaptation in specific agro- climatic region (Abberton et al., 2016). The main objective of plant breeding is to bring new varieties. Plant breeding has been found as a successful tool in increasing yield (Dixon et al., 2006). Plant breeding actually helps in developing new cultivars with enhanced traits that are better suited to adapt to climate change that may be either by conventional or genomic technologies (Habash et al., 2009). Different varieties can be developed using techniques that ranges from simply selecting plants in farmers' fields with desirable traits for propagation, to more classical or molecular techniques to cope with climate change (GIPB, n.d.).

Plant breeding ensures food security and safety under critical weather by developing resistant cultivars, and traits include drought and temperature stress resistance; resistance to salinity, water logging, pests and diseases (Era and Islam, 2019). Historically, it has been found that breeding for drought resistance is the most important objective of several breeding programs for all major crops (Ceccarelli et al., 2007; Ceccarelli et al., 2004). Changes in phenology or enhanced responses to elevated CO₂ are included in the opportunities for new varieties with increased drought tolerance. It has been shown that thermal tolerance is proportional to magnitude of temperature variation experienced: lower thermal limits differ more among species than upper thermal limits (Ceccarelli et al., 2010; Addo-

Bediako et al., 2000). So, Barley which has colonized a wide diversity of thermal changes can harbor enough genetic diversity to breed successfully for enhanced thermal tolerance (Ceccarelli et al., 2010).

In this challenging scenario where climate change has increased: frequency of drought, temperature reducing crop productivity, CO₂ concentration, salinity affected area, frequency of biotic stress (Ceccarelli et al., 2010). It is clear that we need miscellaneous strategies for developing climate-resilient cultivars and expedite the rate of genetic gains (Varshney et al., 2011). To identify adaptable traits to variable environmental condition triggered by climate change, to understand physiological, genetic and molecular mechanisms that allows plant to adapt and respond climate change is the major objective of next generation breeding (Taranto et al., 2018).

3. PLANT BREEDING TECHNOLOGIES FOR CLIMATE CHANGE

To tackle with climate change, the key elements are genetic diversity and plant breeding, and one of the best paths for sustainable food production is integration of plant breeding in climate change strategies (GIPB, n.d.).

Table 3: Genetic technologies for crop improvement (Henry, 2020)

Technology	Dates from (approximate date of first use)	Length of use (approximate number of years of use)	Contribution to crop improvement
Phenotypic selection	Crop domestication	10 000	Eco geographical adaptation
Cross breeding	1900	100	Strong yield increases, adaptation to agronomic improvement and climatic fluctuations
Genetic manipulation	1970s	40	Reduction of dependency on agrochemicals
Molecular markers	1980s	30	Resistance breeding
Genomic Selection	2010s	10	Increased rate of genetic gain
Gene editing	2015	5	Novel products

4. PLANT BREEDING TECHNIQUES FOR ADOPTION TO CLIMATE CHANGE IN AGRICULTURE PRODUCTION

4.1 Advancement in genetic tools

DNA Sequencing technologies has been continuously advancing and it includes: optical mapping, chromosome level assembly tools, improved scaffolding, increased output and reduced costs for long read sequencing, longer reads, assembly of longer contigs, reduced sequencing costs for short read sequencing (Bellott et al., 2018; Bocklandt et al., 2019; Pan and Lonardi, 2019; Díaz et al., 2018; Dong et al., 2018; Belser et al., 2018; Chalupowicz et al., 2018; Jayakumar and Sakakibara, 2019; Tedersoo et al., 2018). Thus, this gives an ever more cost-effective option to characterize available genetic diversity and also makes the mechanism of climate adaptation and application in crop breeding more acceptable (Henry, 2020). The discovery of the genetic basis of the traits is supported by the genes for traits that will support the breeding of genotypes better adapted to new environment and also the molecular basis of resistance to heat, cold, drought, salt and biotic stress is being advanced by genetic analysis, but still it needs efforts in response to recent improvements in genetic technologies (Nepal et al., 2017; Henry et al., 2018; Wisniewski et al., 2014; Cattivelli et al., 2008; Ganie et al., 2019).

4.2 QTL Mapping and Marker Assisted Selection

It includes identification of elite DNA molecular markers, that have correlation with given traits in segregating populations allowing emplacement of QTLs in linkage groups that are beneficial in breeding

program. Till date numerous QTL analysis have been developed (Taranto et al., 2016). Marker assisted Selection (MAS) is the process of indirect choosing for the gene/QTL primarily based on molecular markers linked to the gene. Molecular markers are also used for negative selection i.e. eliminating the effect of the gene that is carried out by the undesirable gene, environmental stress on the plant physiology and biochemical activities. MAS is crucial in the breeding for disease resistance which are also sometime incurred due to the climate change. Molecular markers help in the selection for resistance during the seedling stage. MAS assists in the development of the elite lines with the favorable alleles at target loci found in the elite germplasm. Indirect selection of MAS enhances the effectiveness of selection as it avoids the impact of the environmental stress and climate change. Accurate determination of individual plant genotype can be determined which allows in the selection of the single plants even in early segregation generations which ultimately reduce population size allowing mapping of QTLs.

4.3 Mutation breeding

Chemically induced mutagenesis and DNA screening techniques resulted Targeting Induced Local Lesions in Genome (TILLING). Mutation breeding has been proved as an effective tool as well as approaches for the discovery of allelic variants that are responsible for crop adaptation under abiotic and biotic stresses because of climate change (Kurowska et al., 2011b; Mousavi-Derazmahalleh et al., 2019).

4.4 Gene editing

Gene editing allows gene transfer, directed mutagenesis and control over expression. Widely applied gene editing can be used to directly generate new varieties, and it can provide a useful tool for testing phenotype conferred by alleles discovered in germplasm, determining the functional role of synthetic alleles or wild populations of environmentally adapted germplasm (Henry, 2020). Gene editing has been applied to breed crops adapted to tropical climates (Haque et al., 2018).

5. SOME OTHER METHODS OF PLANT BREEDING TO TACKLE WITH CLIMATE CHANGE

5.1 Improve adaptation

To cope with the challenges posed by climate change, one of the fundamental breeding strategies is to improve adaptation to what will probably be a shorter crop season by matching phenology to moisture availability (Ceccarelli et al., 2010). Experimental evolution has been done to test the hypothesis that outcrossing populations are able to adapt more rapidly to environmental changes than self-fertilizing organisms (Morran et al., 2009). To adapt to a novel environment, a more effective means of recombination and thereby generating the variation is the major advantage provided by outcrossing (Crow, 1992).

5.2 Genetic diversity

Biodiversity has been referred as the raw material for crop improvement. Over centuries, resource-poor farmers have been using genetic diversity intelligently for developing varieties adapted to their own environmental condition caused by climate change which also concludes that genetic diversity is the foundation for sustainable development of new varieties for present and future challenges (GIPB, n.d.). Example includes use of common beans biodiversity by plant breeders to develop both heat and cold tolerant varieties from hot Durango region in Mexico to cold high altitudes of Colombia and Peru (GIPB, n.d.). Through the establishment of a self-regulating plant-pathogen evolutionary system, adaptation to disease is allowed by genetically diverse population (Allard, 1990). It's example is: In barley, for resistance to scald caused by *Rhynchosporium secalis* where a reversal from an excess of susceptible families in the earlier generations to a greater proportion of resistant families after 45 generations was observed (Muona et al., 1982).

5.3 Protected agriculture

Changing and variable climate can be avoided through protected agriculture i.e. moving agricultural production in protected environment which is considered the last resort but is likely to be an option that becomes more important in today's world where food demand is increasing and climate change has been advanced (Henry, 2020). It involves moving to a completely controlled intensified production environment or production in a greenhouse in vertical farming (Eaves and Eaves, 2018). But in development of vertical farming, lack of suitable varieties may be a major barrier (Henry, 2020). Breeding plants for protected agriculture can have a series of objectives since crops are

selected for optimal performance in the environment and breeding of plants with increasingly exact performance optima is provided by technology to deliver increasingly controlled environments (Henry, 2020).

6. CHALLENGES IN PLANT BREEDING

The earliest form of Plant breeding was domestication that help in producing crops that benefits human as well as animals. Today there is great improvement in plant breeding and crop improvement has made possible to gain production in sustainable level but still greater advancement in yield and crop quality is not appreciable (Snape, 2004). With the motive of increasing yield and other yield parameter, different breeding techniques have been developed. Along with enhancement of breeding techniques, some challenges have also evolved. Genetic erosion is defined as absolute loss in crop, variety or allele, reduction in richness and evenness (Ford-Lloyd, 2004; Hammer et al., 1996; Van De Wouw et al., 2009; Willeman et al., 2007). Simply it can be said as loss of variation in crops. The advance scientific plant breeding has its main role in increasing yield and quality and homogeneous new varieties as a rule, which has been widely accepted and distributed by and to farmers and hence replaced land races (Hammer and Teklu, 2008). And yield is the characteristics to choose variety by farmers (Heisey and Brennan, 1991). Hence genetic erosion has been a challenge in plant breeding.

7. CONCLUSION

At present context, since climate change has been serious predicament that has already taken over agricultural production and food security, challenges for plant breeders has intensified. In this scenario, where climate change has started to disrupt food quality, availability and accessibility, plant breeding tools seems to be most effective tool to combat impact of climate change in agricultural production. As Future food production relies on development of new crop varieties including novel crops, breeders has been developing new tools, technologies to cope with climate change. The plant breeding technologies like: QTLs mapping allows screening of elite germplasm under the stressed climate, molecular markers that contributes to crop improvement through resistant breeding, speed up the breeding progression, genomic editing tool CRISPR/Cas9 tools can be utilized to abolish of genome edited non transgenic plant to cope up environmental stress ensuring food security, genomic selection that contributes by increasing rate of genetic gain has been boon companions for plant breeders. Breeders are working to create genetic diversity since genetic diversity is primal matter for crop improvement that can minimize the production problem brought by climate change. Plant breeding approach are the promising and successful approaches for enhancing food security, crop improvement under various weather conditions by developing resilient and stress resistance variety. Molecular plant breeding can be sustainable approach to speed up the yield in the presence of biotic and abiotic stresses than conventional breeding.

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