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Devising an Appropriate Breeding Strategy for Different Crops to Face the Challenge of Climate Change

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ABSTRACT

Work on global warming is expected to have significant impacts on conditions affecting agriculture, including temperature, carbon dioxide, glacial run off, precipitation and the interaction of these elements has been reviewed in this article. To a large extent, the overall effect of climate change will depend on the balance among these factors. Assessment of the effects of global climate changes on agriculture will help to properly anticipate and adapt farming systems to maximize agricultural production. There is exponential rise in atmospheric carbon dioxide. Atmospheric concentration of carbon dioxide was 270 ppm during pre-industrial period and human activities have added more than 100 ppm and it has reached 380 ppm with the rate of rise as high as 1.8 ppm per year. With this exponential rise in carbon dioxide, its concentration will double by the middle of 21st century. The effects of an increase in carbon dioxide would be higher on C3 plants (such as wheat) than on C4 plants (such as maize), as the former is more susceptible to carbon dioxide deficit. Increased CO_2 leads to fewer stomata development in case of plants which results in less water usage. It is estimated that under optimum conditions of temperature and humidity, the yield increase could reach 36 % if the levels of CO_2 are doubled. A large number of stress responsive genes have been cloned and sequenced from a number of crop plants. A common feature of many stress induced proteins is that their transcripts are induced not only by stress but also by (ABA) abscisic acid. It implies that there is a general role for ABA in the signal transduction pathway i. e. from sensing of the environmental stress and thereby leading to gene expression.

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Introduction

The world today faces great challenges to produce adequate food, fiber, feed, industrial products and ecosystem services for the globe's 6.7 billion people (Raja Reddy and Kakani, 2008). Global warming is expected to have significant impacts on conditions affecting agriculture, including temperature, carbon dioxide, glacial run off, precipitation and the interaction of these elements. To a large extent, the overall effect of climate change will depend on the balance among these factors. Assessment of the effects of global climate changes on agriculture will help to properly anticipate and adapt farming systems to maximize agricultural production. Agriculture not only produces significant effects on climate change, mainly through release of greenhouse such as methane and nitrous oxide, but it is also involved in changing earth's land cover which can affect its ability to absorb and reflect light. Land use changes such as deforestation along with overuse of fossil fuels are the major sources of anthropogenic production of carbon dioxide (Anonymous, 2007). There is exponential rise in atmospheric carbon dioxide. Atmospheric concentration of carbon dioxide was 270 ppm during pre-industrial period and human activities have added more than 100 ppm and it has reached 380 ppm with the rate of rise as high as 1.8 ppm per year (Uprety, 2008). With this exponential rise in carbon dioxide, its concentration will double by the middle of 21st century. The increase in atmospheric carbon dioxide leads to global warming by absorbing long wave radiations from the earth's surface and it can also affect cloudiness and precipitation (climatic effect).

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Effects of climate changes on crop productivity

- Less production per unit area in terms of quantity and quality of crops due to adverse effects of drought on crop growth.
- Agricultural production practices are adversely affected on account of less availability of water for irrigation.
- In low lying areas, flood water accumulates which adversely affects the genetic mechanisms of the crop plants.

In addition to it, agricultural productivity may be affected by severity and pace of the climate change. If change is gradual, there may be enough time for biotic adjustment. However, rapid climate change may harm agriculture in many countries, especially that are already suffering from poor soil and climate conditions as there will be less time for optimum natural selection and also pressure.

Schneider et al. (2007) reviewed literature on key vulnerabilities to climate change and concluded that for 1 to 3^{o} C mean global temperature increase (by 2100 as compared to 1990-2000), there would be productivity decreases for some cereals in low latitudes, and productivity increases in high latitudes. With medium confidence, global production potential was predicted to be:

- Expected to increase when increase in temperature is up to 3^{o} C.
- Very likely to decrease when increase in temperature is above 3^{o} C.

Most of the studies on global agriculture reviewed by Schneider et al. (2007) had not incorporated a number of critical factors including changes in extreme events or biotic factors like insect pests and diseases. These studies had also not considered the development of specific priorities to aid selection.

Likely impacts in different continents

During 2007, IPCC (Intergovermental Panel on Climate Change) had projected with medium confidence that by the mid-21st century, east and south-east Asia, crop yields could increase up to 20 % while in central and south Asia, yields could decrease up to 30 %. Taken together the risk of hunger was projected to remain very high in several developing countries.

From 2000 to 2003, grain stocks have been dropping and consequently resulting in a global grain harvest that was short of consumption by 93 million tons in 2003. During 2002, India and the United States suffered sharp reductions because of record temperatures and drought.

Poverty Impacts:

At the Overseas Development Institute (ODI), research workers have investigated the potential impacts that climate change would have on agriculture and the way it would affect it would affect the attempts to alleviate poverty in developing world. These workers argued that the effects from moderate climate change are likely to be mixed for developing countries. Poor people in developing countries are vulnerable to short term impacts, notably the increased frequency and the severity of adverse meteorological conditions is likely to have a negative impact. It should be taken into account while framing agricultural policy (ODI, 2007).

Effect of elevated carbon dioxide on crops

It is common knowledge that carbon dioxide is essential to plant growth. Increased CO_2 levels are expected to have positive physiological effects by increasing the rate of photosynthesis. As already mentioned, the amount of carbon dioxide in the atmosphere is 380 ppm whereas amount of oxygen is 210,000 ppm which means that plants are often starved of carbon dioxide due to the enzyme that fixes CO_2, rubisco also fixes oxygen in the process of photorespiration. The effects of an increase in carbon dioxide would be higher on C3 plants (such as wheat) than on C4 plants (such as maize), as the former is more susceptible to carbon dioxide deficit. Increased CO_2 leads to fewer stomata development in case of plants (Woodwards and Kelly, 1995) which results in less water usage. It is estimated that under optimum conditions of temperature and humidity, the yield increase could reach 36 % if the levels of CO_2 are doubled. Few studies have taken into account the impact of elevated carbon dioxide concentrations on the farming systems as a whole. Majority of the models study the relation ship between CO2 and productivity in isolation from other factors associated with climate change such as increased frequency of extreme weather events, seasonal shifts, and so on (Anonymous, 2010).

Effect of climate change on quality

The effects of climate change on grain and forage quality emerges from new research. amylose content, that is major determinant of cooking quality in rice grain, increases under elevated CO_2. The rice grains cooked from plants grown in high-CO_2 environments are firmer than that from plants grown in the present day environments. But the concentrations of iron and zinc, which are very important component of human nutrition, would tend to be lower. Grain protein content decreases under combined increases of temperature and CO_2. Studies have shown that increases in CO_2 concentration lead to decreased concentrations of micronutrients in crop plants (Loladze, 2002). It is going to have a knock-on effects on other parts of ecosystem as herbivorous animals will consume more food to gain the same amount of protein (Carlos and Trumble, 1999).

Devising appropriate breeding programs

Raja Reddy and Kakani (2008) observed that agricultural roduction and productivity are highly sensitive to changes in climate and weather conditions. Hence changes in regional and global climate, especially the climatic variability, have been involved in affecting local and global food, fiber and forest production. Future crops may be subjected to the environments for which these have not been bred. Genotypic variability is hotly sought after for various traits to improve crop growth and development as well as tolerance to abiotic stresses. This constitutes the basis for improving crop yields in a traditional breeding program. With availability of improved techniques in functional genomics, it has become easier to manipulate traits controlling tolerance to various abiotic stresses and/or to develop ClimateReady crop plants. However, these techniques have their drawbacks affecting yield and quality because of their pleiotropic effects have adverse effects on yield as well as quality. Therefore, an understanding of the abiotic stresses at the whole plant level is essential. Trait selection through a sound understanding of physiological basis of plant responses to abiotic stresses is vital in stead of wildly playing with genes and their transcription factors. This would help to save resources, such as time and money, both in private and public sector.

Just in the last one century, average increase in the earth's temperature has been 1^o F. From region to region, agricultural crops are likely to show differential response to climatic changes induced by greenhouse gases. For example, average crop yield is expected to drop down to 50 % in India and Pakistan according to the UKMO scenario whereas corn production in Europe is expected to grow up to 25 % in optimal hydrological conditions. Agriculture plays an important role in mitigating some greenhouse gas emissions, it reduces CO_2 emissions by 32 % (Uprety, 2008). However, agriculture contributes in a big way to increase methane and nitrous oxide concentrations in the atmosphere. Consequently, southern Africa would lose more than 30 % of its main crop, maize and in south Asia, losses of its many regional staples, such as rice, millet and maize could be more than 10 % (Lobell et al., 2008). At present, India is facing great challenges to produce enough food, fiber and agro-industrial products to feed its teeming millions. Since no new cultivable area is likely to become available, the increased food supply will have to be arranged from designer varieties and more intensive agriculture production and protection technology in the existing arable land. Moreover, country's water resources are also limited and hence increasing population demands may result in less availability of water for agricultural purposes. At present, greenhouse emissions are increasing in the atmosphere due to anthropogenic activities. Activities associated with agriculture produce significant greenhouse gases such as carbon dioxide, methane and nitrous oxide. Carbon dioxide is the principal heat-trapping gas and hence causing global-warming (Lal, 1997). Consequently, the world-wide warming carbon is of primary and basic importance. Plants have been directly affected by rising atmospheric CO_2 because of the presence of rubisco, the key enzyme for photosynthesis (Uprety, 2008). C4 plants show little response to the elevated CO_2 because C4 pathway is not competitively inhibited by O_2 and is completely CO_2 saturated. Response of crop plants such as Brassica, rice and wheat has been studied in terms of photosynthesis and productivity (Uprety and Reddy, 2008). Crops like Brassica showed amelioration of the adverse moisture stress effect at high concentration of CO2 by increasing the water status of plants and greater root growth (Uprety et al., 1995). The transfer of the CO_2 responsive characters from the parents *B. campestris* to the hybrid *B. oxycamp* has been studied (Uprety et al., 1998). It was observed that use of biotechnological techniques to understand the role of photosynthesis repression genes and the role of glucose signaling associated with hexokinase located at plasma lemma or tonoplast to regulate photosynthesis under elevated CO2 need to be studied. Identification of HIC (high CO_2) *Arabidopsis*, that carry a 3 keto acyl coenzyme A synthetase gene, which encodes a negative regulator of stomatal development, has been studied (Gray et al., 2000). It was emphasized by Uprety (2008) that increasing CO_2 levels may present opportunities to breeders to select for efficient translocation of assimilate away from leaves towards roots. Further there is need to understand physiological mechanisms involved in down regulation of rubisco and genetic control on these processes. Impacts of interactive effects of elevated CO_2, ozone, temperature, drought and UV-B radiation (280-320 nm) also need further investigation especially impact assessment analysis for yield and total biomass production. Latest biotechnological developments allow genetic manipulations of plant characters. It has become possible to manage over and under expression of individual genes and also the introduction of novel genes by bringing about changes in basic metabolism and growth as affected higher atmospheric CO_2. It may assist in developing plants for future high CO_2 environment. These genetically developed plants will be powerful tools for studying plant responses to elevated CO_2 and consequently help in identifying plant type for future CO_2 enriched environments.

More favorable effects on yield tend to depend to a large extent on realization of the potentially beneficial effects of carbon dioxide on crop growth as well as increase in water use efficiency. Decline in the potential yield may generally be caused by shortening of growth period, decrease in nutrient availability and poor vernalization.

Historic perspective: **Abiotic Stresses**:

Abiotic environmental factors confronted by the plant are considered to be the main source of yield reductions. The abiotic stresses are those which determine the extent to which the yield potential of a crop or culture is realized if all other biotic factors are controlled. Environmental factors may be stressful because they may be in limited supply (sub-optimal) supply or in excess supply (supra-optimal). Exposure to extremes of temperature and drought are one of the most severe stresses limiting crop growth and productivity. Research workers have identified morphological, physiological and anatomical characteristics which enable plants to grow in stressed environments (Levitt, 1980a and b; Ludlows and Muchow, 1990; Acevado and Fereres, 1993; Basra and Basra, 1997a). Scientists have done studies on how the plants perceived environmental stresses and how this physiological signal is transduced by a chain of processes that operate either directly on metabolism or by modifying gene expression and the temporal and spatial hierarchy of the responses of the plant. A large number of stress responsive genes have been cloned and sequenced from a number of crop plants (Basra and Basra, 1997b). A common feature of many stress induced proteins is that their transcripts are induced not only by stress but also by (ABA) abscisic acid (Chandler and Robertson, 1994). It implies that there is a general role for ABA in the signal transduction pathway i. e. from sensing of the environmental stress and thereby leading to gene expression. To understand this complex network of gene activation requires major studies. Basra and Basra (1997b) further observed that a successful strategy to alleviate the detrimental effects of cellular dehydration stress as experienced during drought, salt or cold stress is through engineering of compatible solutes or osmoprotectants to maintain the water potential of the cell, the biosynthesis pathways have been established and the corresponding genes cloned for several osmoprotectants such as mannitol, trehalose, cycline betaine and proline from bacterial, yeasts and higher plants. A bacterial gene mt1D involved in the biosynthesis of mannitol was introduced into tobacco behind a constitutine promoter 4 and the transgenic plants were assayed for salt resistance (Tarczynski *et al*., 1993). It was reported that no differences were observed between control and transgenic plants under non stress conditions. But after 30days of exposure to to salinity, transgenic plants producing mannitol had longer shoot height and also initiated new and longer roots, while those of the control plants turned brown and did not elongate or branch. Over-expression of pyrroline-5-carboxylate synthetase increases proline production and confers osmotolerance in transgenic plants (Kishore *et al*., 1995). It is quite possible that the effect of osmoprotectants could be synergistically enhanced by production of stress proteins in the transgenic plants.

At high temperature, obvious effect is seen on poor stand establishment, reduction of crop duration due to accerelated development of plant as a whole leading to decreased biomass and yield (Saxena and Malhi, 1997). Besides, it was observed that there is reduced turgidity of leaves and their rapid senescence in addition to abscission of lower leaves that affects availability of energy leading to overall reduced crop duration. Extreme temperature stress causes death of cells, tissues, organs or whole plant due to intensive solar radiation. Such type of symptoms are typical to the heating of organs that lack transpirational cooling. Seedlings can be injured more by heat and seedling mortality is a well known problem. Reproductive phase of the plant is especially sensitive to heat and there can be flower abscission , pollen sterility, tassel firing, leaf firing and poor seed set leading to drastic yield reductions. High temperature also reduces duration of grain filling causing thereby reduced grain size.

The role of various cellular solutes in protectin g proteins against denaturation has been suggested (Levitt, 1980a). Solutes such as organic acids and hormones such as kinetin have been shown to exercise protection. It has been observed that plasma membranes are far more heat tolerant as compared to photosynthesis processes which are extremely sensitive as compared to the respiration processes. In addition to cell membrane thermostability, leaf soluble proteins, praline and soluble sugars are important components of heat tolerance.

Raja Reddy and Kakani (2008) also observed that high temperature is the most imminent threat from climate change and its effect on plant growth, development and yield has been widely studied. The most commonly used trait to screen for high temperature tolerance is Cell Membrane Thermostability (CMT). It is an indicator of the vegetative phase tolerance. However, fruit-set and pollen germination are indicators of reproductive parts tolerance to high temperature. Over the years, correlation between CMT and pollen germination was compared in several crops. However, a genotype with higher CMT along with higher optimum and maximum temperatures for pollen germination and pollen tube growth would be useful. The lower RI would help the membrane to tolerate high temperatures. A further evaluation of the available germplasm and wild relatives of the species of interest is essential to develop high temperature tolerant crops or crop cultivars.

In sugarcane, Sukhchain et al. (2003) studied effect of flooding in spring planted crop and observed that flooding tended to enhance the direct effect of stalk length but tended to diminish the direct effect of stalk number on cane yield. However, in autumn planted crop, flooding tended to enhance the direct effect of stalk weight and to diminish the direct effect of stalk number on cane yield. In autumn crop, only cane yield and sugar recovery had high direct effects on commercial cane sugar. Although stalk number tended to decline, yet there was enhancement in sugarcane weight. Consequently, crop productivity was enhanced. Sukhchain and Thind (1997) studied the effects of water-logging on sugarcane yield and commercial cane sugar in plant cane crops and first ratoon crop stages. For plant crop, combined analysis of variance revealed that plant crops in the autumn season gave higher cane yield and commercial cane sugar under flooding as compared to the normal environment whereas the spring crop gave lower cane yield and commercial cane sugar. Ratoon crops showed a favorable response to flooding and gave significantly higher cane yield and commercial cane sugar under flooding both in autumn and spring seasons. Flooding had little effect on sugar recovery in plant or ratoon crops in either season. Sukhchain and Saini (1998) studied the effects of water-logging and high water table conditions on cane yield, commercial cane sugar and sugar recovery in plant cane, first ratoon and second ratoon stages. Variety CoS 8118 which had thin stalks, profuse tillering and high ratoonability (traits possibly inherited from *Saccharum spontaneum*) was found to be superior to the other varieties for cane yield and commercial cane sugar.

In case of rice, Sukhchain (2005) studied the effects of flooding on various morphological traits in eight varieties. While plant height and panicle branch number tended to increase, tiller number, panicle number and flag leaf angle tended to decline under flooding. However, flooding had no significant effect on paddy yield and panicle length as well as length and breadth of flag leaf. Dhaliwal and Sukhchain (1997) studied the flooding tolerance of 148 genotypes of wheat at 40, 72 and 82 days after sowing for 3, 6 and 20 days, respectively. Twenty-one genotypes survived after flooding stress. The other genotypes were found sensitive and died due to prolonged (20 days) flooding at reproductive phase. On the basis of grain yield and 1000-grain weight, varieties CPAN-1897, CPAN-4027, CPAN-2144, Carpintero and PBW-154 were found more tolerant than WH-542 and PBW-343 under flooding conditions. Bains et al. (1999) evaluated accessions of rye and wild wheat, i. e., *Secale Cereaele* (6), *Aegilops bicornis* (2), *Ae. columnaris* (2), *Ae. cylindrica* (23), *Ae. lorentri* (11), *Ae. kotschyi* (1), *Ae. longissima* (6), *Ae. ovata* (15), *Ae. speltoides* (37), *Ae squarrosa* (600, *Ae. triaristata* (55), *T. boeticum* (55), *T. diccoides* (8), and *T. urartu* (36) under 15 cm water in 13 flooding dykes. Dykes were flooded for 3, 6 and 20 days, respectively, i. e. 50, 80 and 120 days after sowing. Flooding for 3 and 6 days, respectively, 50 and 80 days after sowing produced no visible effect on test accessions. However, for 20 days continuously 120 days after sowing had a drastic effect on most of the accessions. Fifty accessions of different species were totally submerged in water and probably died due to submergence. Only seven accessions of *Ae. speltoides*, namely, 3582, 3593, 3594, 3597, 3599, 3600 and 3603 survived.

Dhaliwal and Sukhchain (1998) studied the effect of saturated moisture conditions on various genotypes of lentil. Twenty genotypes of lentil were kept in saturated moisture conditions 90 days after sowing for 35 days at flowering stage. Genotypic differences for excess water stress tolerance were evident. Ten lines, namely, DPL-55, PL-4, K-75, IPL-68, LL-699, LH-84-8, 29101, LL-492, LL-56 and LL-147 survived excess water stress. Under saturated conditions, LL-699, LL-147 and LL-492 were top entries and showed comparatively less reduction in yield.

Future plan of action

1. There is need for screening and genetic enhancement of major crops for tolerance to abiotic stresses associated with climate change using controlled environmental conditions. Such traits can be incorporated using conventional breeding techniques and also molecular tools. Proiority Crops: Wheat, Maize, Rice, Cotton, Pigeonpea, Chickpea, Brassica including other oilseed crops.
2. There is need to study physiology and biochemistry of abiotic stress tolerance in major crops under various combinations of enhanced CO_2 including other green house gases, temperature, drought and flooding, etc. The relevant physiological and biochemical traits can be effectively utilized.
3. Changes in pattern, intensity and racial diversity of disease pathogens and insect pests of wheat, rice and cotton also require intensive study. Virulent genes conferring resistance to these identified biotypes posing a serious critical danger should be incorporated in the relevant crop.
4. Studies are required to be initiated on impact of climate change on nutrient availability; development of crop production package for enhanced nutrient use efficiency. Germplasm with high nutrient use efficiency can be developed to offset the adverse effects of poor nutrient availability.
5. Furthermore, studies can be undertaken on various aspects of agro-forestry such as:

a) Agro-forestry for amelioration of negative effects of climate change on agroecology.

b) Identification of tree species suitable for drought affected, water-logged and saline areas.

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