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Climate Resilient Maize Varieties for Varied Climatic Conditions

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Climate change refers to changes in the statistical distribution of weather across a period of time that ranges from decades to millions of years. It can be a change in the average weather or a change in the distribution of weather events around an average. Climate change may be limited to a specific region, or may occur across the whole Earth, and this type of climate change has been documented (Sahney *et al*., 2010). Farmers have a long record of adapting to the impacts of climate variability but predicted climate change represents an enormous challenge that will test farmer's ability to adapt and improve their livelihoods (Adger *et al*., 2007). Climate change is a threat to agriculture and food security and there is an urgent need to identify priorities for future research. The relationship between climate change, agriculture and food security, however, is a complex one that is also shaped by economic policies and political decisions. Appropriate climate change research, therefore, involves researchers from a broad spectrum of disciplines along with other stakeholders. Maize and wheat are two of the most important cereal crops in the world and there is increasing concern about the impact of predicted climate change on the production and productivity of these key cereal crops.

Role of Maize for Food Security

Maize is vital for global food security and poverty reduction. Together with rice, maize and wheat jointly provide at least 30% of the food calories to more than 4.5 billion people in 100 developing countries. In Africa, maize is the most widely grown staple crop, and it is rapidly expanding in Asia. The current cultivated area in over 125 developing countries exceeds 100 million ha. About 67% of the total maize production comes from low and lower middle income countries, indicating the vital role the crop plays in the livelihoods of millions of poor farmers. Owing to the growing demand for feed and bio energy, the demand for maize in the developing world is expected to double by 2050 and that for wheat to increase from 621 million tons during 2004 to 2006 to more than 900 million tons in 2050 (Rosegrant *et al*., 2007). Many small-scale maize farmers in Africa, Asia and Latin America cannot afford irrigation even when it is available and, hence, grow maize under rain-fed conditions. The crop is, therefore, very vulnerable to climatic variability and change (Bänziger and Araus, 2007). Historical trends clearly show that maize yields fluctuate more widely from year-to-year than is the case for rice and wheat. The current probability of failed seasons in maize farming systems varies between 8 and 35% (Hyman *et al*., 2008). Production fluctuations often give rise to price fluctuations that can adversely affect both poor producers and consumers.

Impact of Climate Change

Climate change is likely to lead to increased water scarcity in the coming decades (Lobell *et al*., 2008; Hendrix and Glaser, 2007). Changes in precipitation patterns will lead to more short-term crop failures and long-term production declines. Water scarcity, due to a reduction in rainfall, is projected to become a more important determinant of food scarcity than land scarcity and the resulting decline in global per capita food production will threaten future food security (Brown and Funk, 2008; Gleditsch *et al*., 2006). In some regions, changes in rainfall distribution will result in temporary excessive soil moisture or water logging in maize production areas. Currently water logging regularly affects over 18% of the total maize production area in South and Southeast Asia. Climate change is also likely to lead to an increase in temperature. Climate models show a high probability (>90%) that by the end of this century, growing season temperatures will exceed the most extreme seasonal temperatures recorded in the past century (Battisti and Naylor, 2009). In Sub-Saharan Africa, maximum temperatures are predicted to increase by an average of 2.6°C across maize mega-environments (Cairns *et al*., 2012). While an increase in temperature of a few degrees is likely to increase crop yields in temperate areas, in many tropical areas even minimal increases in temperature may be detrimental to food production. High temperatures result in a reduction in crop yields by affecting an array of physiological, biochemical and molecular processes. Sensitivity to supra-optimum temperatures and mechanisms of tolerance depend on the severity, duration and timing of heat stress together with the developmental stage of the plant. The most significant factors associated with yield reduction under heat stress are increased sterility, shortened life cycle, reduced light interception and the perturbation of carbon assimilation processes (photosynthesis, transpiration, and respiration) (Reynolds *et al*., 2010). The effect of a combination of stresses such as heat and drought stress on crop yields will be greater than the effect of each stress individually.

Increasing temperatures and a higher frequency of droughts and flooding will also affect ecosystem resilience, increasing outbreaks of pests and diseases (Young and Lipton, 2006). Temperature influences insect development, survival and distribution. As temperatures increase, insect populations are likely to increase and diversify. Climate changes will also influence the development of maize and wheat diseases, with increasing temperatures and incidents of drought exacerbating plant stress and increasing plant susceptibility (Garrett *et al*., 2011; Savary *et al*., 2011). Climate represents the key agro-ecosystem driving force of fungal colonization and mycotoxin production (Paterson and Lima, 2010). If the temperature increases in cool or temperate climates, the relevant regions may become more susceptible to aflatoxins. Maize is particularly vulnerable particularly to climate change as exemplified by outbreaks of lethal aflatoxicoses in Kenya (Lewis *et al*., 2005).

Climate Change Adaptation and Mitigation Options

Climate change poses huge challenges to food security and the livelihood security of millions. Thus, development and dissemination of improved germplasm and risk-reducing management options have the potential to offset some of the yield losses linked to climate change. Communities may adapt in different ways, including switching to water efficient or drought and heat tolerant crops better suited to a warmer and drier climate (Lobell *et al*., 2008) and/or diversifying livelihood strategies across crops and livestock (Seo, 2010). Food security in an era of climate change may be possible if farmers transform agricultural systems via the use of improved seed and fertilizer along with improved governance (Brown and Funk, 2008). Models of the global food economy suggest that trade will also represent an important but not complete buffer against climate change induced yield effects (Rosenzweig and Parry, 1994).

The International Wheat and Maize Improvement Center (CIMMYT) together with international and national agricultural research institutes are working to develop maize and wheat technologies for climate vulnerable countries. Work on maize in Africa is coordinated with the International Institute of Tropical Agriculture (IITA).

Maize: The development of climate-adapted germplasm is possible through a combination of conventional, molecular and transgenic breeding approaches. In conventional breeding for tropical maize, the application of proven drought breeding methodologies in managed stress screening has resulted in significant grain yield increases under drought stress (Bänziger *et al*., 2006). Hybrids developed through CIMMYT's stress tolerance breeding program have a yield advantage of up to 20% compared to commercially available hybrids (Bänziger *et al*., 2006). In maize, donors with increased tolerance to drought stress have been identified and are being incorporated into the breeding pipeline. Furthermore, novel alleles associated with drought, heat and water logging tolerance, and stress combinations have also been identified using the latest advances in whole genome sequencing. Together these developments should speed up the development of climate adapted maize germplasm. Within the primary maize and wild relatives gene pool there exists unexploited genetic diversity for novel traits and alleles (Ortiz *et al*., 2009) that can be used for breeding new high yielding and stress tolerant cultivars using conventional approaches. Where limited genetic variation in maize exists for biotic and abiotic stress tolerance, transgenes will provide the opportunity to increase genetic variation into breeding programs (Juma, 2011). On-going research at CIMMYT suggests that large genetic variation exists within tropical maize for adaptation to heat stress and that a breeding program can take advantage of this. More research is needed on the interaction of heat and drought stress in cereals (Barnabás *et al*., 2008).

Changing environment is regarded as a major threat to crop productivity, worldwide. To mitigate the effect of climate change, there is the need to develop matching crop varieties and production/protection technologies. New innovative approaches, such as conservation agriculture (CA), precision agriculture (PA), and biotechnology (BT), hold great promise for sustaining agricultural production. Conservation agriculture involves techniques of "no tillage" and crop residue management (recycling) and helps conserve natural resources such as water, soil, and nutrients. Several CA technologies have been developed, for example, zero tillage (no tillage), raised-bed planting, tensiometer, laser land leveling, happy seeder, rotavator. The "precision agriculture" is the need of the hour to apply right amount of inputs, at right time, at right place, and in right manner with right hardware. Several techniques ensuring "precision agriculture" have been developed and are being commercialized. Most popular technologies include: drip irrigation and fertigation, leaf color chart for need-based application of nitrogen, sensor-based yield monitors; nitrogen sensors/green seekers, special-purpose vehicles with sensor-based input applicators; integrated nutrient management (INM) systems, integrated pest management (IPM) systems, integrated disease management (IDM) systems, site-specific management systems using remote sensing, geographical positioning system (GPS), and geographical information system (GIS), Web-based decision support systems for controlling diseases and insect pests, germplasm enhancement for biotic and abiotic stress management. Conservation agriculture can also facilitate sequestration of carbon. One way of mitigating CO_2 concentration in the atmosphere is through carbon sequestration in the above ground biomass and in the soils, hence directly contributing to climate change mitigation.

"**Seed is the carrier of technology**"; therefore, plant breeding involving innovative approaches of biotechnology can play a dominant role in developing climate resilient varieties. A series of high-yielding crop cultivars possessing resistance to diseases and insect pests and with improved quality have been developed following the conventional methods such as introduction, selection, hybridization, polyploidy, and mutation breeding. However, these methods are very time consuming and laborious. Moreover, it has been rather difficult to develop improved varieties in vegetatively propagated and seedless crops. Plant genetic engineering and DNA marker technologies have now become a valuable adjunct in crop improvement for rapid precision breeding for specific purposes.

Maize and wheat are among the three most important crops for global food security. Climate change will have variable impacts of supply and demand patterns for these crops. While wheat production may expand in high latitude temperate regions, global warming will reduce production in low rainfall tropical growing regions. Maize production in the developing countries will suffer significantly from climate change. Climate change will therefore undermine food and livelihood security and complicate efforts to fight poverty, hunger and environmental degradation. Adaptation options include the following:

1. Technological strategies (investment in research and development of stress tolerant and widely adapted crop varieties, irrigation and natural resource management options).
2. Policy options (finance, weather index insurance, strategic food reserves, etc.)
3. Capacity building (institutional plus physical infrastructure including water storage, irrigation systems, food storage, processing, forecasting and disaster preparedness).
4. Income diversification (within and outside of agriculture).

Despite some uncertainties on the spatially differentiated impact of climate change on agricultural production, there is little doubt that new germplasm, more suited to future climates, is critical along with improved agronomic and crop management practices. There is an urgent need to develop climate-adaptable crop varieties with improved tolerance to heat stress, and combined heat and drought stress. In some cases, climate change may create new biotic stresses brought by new conditions conducive to pest and disease infestations. Decision support systems (crop modelling) may help project any likely effects of climate change on the outbreak and spread of disease and pest epidemics.

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