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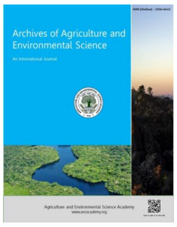

REVIEW ARTICLE

Breeding climate change resilient maize and wheat for food security

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ABSTRACT

Climate change is affecting agriculture directly or indirectly, worldwide and is an important challenge that threatens the long-term production growth of cereals. Fluctuating temperature, greenhouse gases, rainfall, and high humidity directly affect the crops, pathogens, insects, and weeds. Several new diseases, weeds, and insect pests have started appearing with the changing climate. Maize and wheat are the two of the most important food crops worldwide with too are getting affected. Predictions suggest that climate change will reduce maize and wheat production this will coincide with a substantial increase in demand for maize and wheat due to rising populations. Maize and wheat research has a crucial role to play in enhancing adaptation to and mitigation of climate change while also enhancing food security. The varieties of agricultural crops with increased tolerance to heat and drought stress and resistance to pests and diseases are serious for handling existing climatic variability and for adaptation to progressive climate change. Numerous climate resilient agricultural technologies such as zero tillage (no tillage), laser land leveling, happy seeder, raised-bed planting, tensiometer, and rotavator have been invented for the conservation of agriculture. Further, drip irrigation and fertigation, leaf color chart (LCC) for need-based application of nitrogen, integrated nutrient management (INM) systems, integrated pest management (IPM) systems, integrated disease management (IDM) systems, site-specific management systems using remote sensing, GPS, and GIS, and Web-based decision support systems for controlling diseases and insect pests are being commercialized to mitigate the climate change.

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INTRODUCTION

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. The climate change may be limited to a particular region, or might happen across the entire Earth, and this kind of climate change has been recognized (Sahney *et al*., 2010). The farmers have a very long record of adapting to the impacts of climate variability but forecast of climate change represents a massive challenge that will test farmer's capability 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 and wheat for food security: Maize and wheat are 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. Although considered a temperate species, wheat is the most widely grown of any crop with around 220 million ha cultivated annually in environments ranging from very favourable in Western Europe to severely stressed in parts of Asia, Africa, and Australia (Braun *et al*., 2010). Wheat is one of the most susceptible crops to climate change and is especially sensitive to heat. Poor productivity growth or stagnation in the Green Revolution areas of South Asia and low yields in Africa, coupled with climate change, will make it more difficult to meet the growing demand for wheat (Rosegrant *et al*., 2009).

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. The climate changes will also affect the development of maize and wheat diseases, with enhancing temperatures and incidents of drought exacerbating plant stress and increasing plant susceptibility (Garrett *et al*., 2011; Savary *et al*., 2011). The 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).

The effects of climate change on wheat production will vary greatly depending on region. While future climate scenarios may be beneficial for the wheat crop in high latitudes, global warming will reduce productivity in zones where favorable temperatures already exist, for example in the Indo-Gangetic Plains (IGP) of South Asia. The IGP, currently part of the favourable, high potential, irrigated, low rainfall mega-environment, accounts for 15% of global wheat production. By 2050 and due to climate change, 51% of the region might suffer from a significant reduction in wheat yields unless farmers adopt appropriate cultivars and crop management practices (Ortiz *et al*., 2008).

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) while that on wheat in the West Asia and North Africa (WANA) region is coordinated with the International Center for Agricultural Research in the Dry Areas (ICARDA).

Maize: The development of climate-adapted germplasm is likely through a amalgamation of conventional, molecular and transgenic breeding methods. 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 might be applicable for breeding new high yielding and stress tolerant cultivars through conventional methods. 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).

Wheat: Wheat yields decline at supra-optimal temperatures (Wardlaw *et al*., 1989; Reynolds *et al*., 1994) and significant breeding effort will be required to maintain productivity in regions closer to the equator. Nonetheless, wheat is relatively well adapted to water deficits and is grown widely in semi-arid regions such as Central Asia, Australia, and throughout the Mediterranean region. In regions that become progressively more arid, wheat may become more competitive than crops, such as maize, that are currently grown. Wheat breeding has had considerable impact in marginal environments as well as temperate ones. Recent effort has focused on breeding for earlier maturing cultivars that escape terminal heat stress and encompass resistance to diseases associated with warm humid environments (Joshi *et al*., 2007) as well as the highly virulent Ug99 stem rust strain. One of the most effective research strategies for wheat has been, and will continue to be, to change the phenological pattern of the crop so that critical growth stages do not coincide with stressful conditions or simply to finish the life cycle early before severe stress conditions occur. Another is to lessen the incidence of stress with the development of a good root system that, in the case of drought, permits water to be accessed deeper in the soil and, in the case of heat, allows transpiration rates that better match evaporative demand, thus approving maximal carbon fixation with the added benefit of cooler plants (Reynolds *et al*., 2010). Given the time lag between technology development, deployment and on-farm adoption of new varieties, current research also needs to focus on institutional innovations and policy options that facilitate farmers' access to existing and new germplasm to enhance local adaptive capacity to climate change.

Conclusions

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. Although wheat production might expand in high latitude temperate regions, the global warming will decrease 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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