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A Review of Coping with Climate Change Role of Plant Breeding for Food and Agriculture

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Abstract
Plant breeding efforts to help producers overcome the enormous challenges posed by climate change through the creation of new seed varieties with improved genetics from germplasm exhibiting stress tolerance. However, A 70% increase in food production is required over the next four decades to feed an ever-increasing population. The inherent difficulties in achieving this unprecedented increase are exacerbated by the yield-depressing consequences of climate change and variations and by the pressures on food supply by other competing demographic and socioeconomic demands. With the dwindling or stagnant agricultural land and water resources, the sought-after increases will therefore be attained mainly through the enhancement of crop productivity under eco-efficient crop production systems. 'Smart' crop varieties that yield more with fewer inputs will be pivotal to success. Plant breeding must be re-oriented in order to generate these 'smart' crop varieties.
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Introduction

Plant breeding efforts to help producers overcome the enormous challenges posed by climate change through the creation of new seed varieties with improved genetics from germplasm exhibiting stress tolerance. A report by the European Seed Association entitled Climate Change and the Seed Industry suggests global temperatures may rise by 11 degrees by 2050, and more frequent and severe drought and flooding, along with increased pressure from insects and disease, will be agriculture's biggest challenge. "If increased temperatures, reduced rainfall, and changing rainfall patterns become the norm, then it obviously will impact the types of selections that plant breeders make and the issue becomes one of either the need for better breeding selection methodology or producers changing crop enterprises," says Wayne Smith, chair of the National Association of Plant Breeders Communications Committee. Improvements to in-situ and ex-situ conservation programmes for domesticated species, their wild relatives and other wild genetic resources important for food and agriculture, along with policies that promote their sustainable use, are therefore urgently required.

Advances in technology have put many more tools into breeders' hands. "Technologies like molecular markers and bioinformatics and other techniques are expediting the process of analyzing and assessing traits," says Andy LaVigne, president and CEO of the American Seed Trade Association. It's expected that breeding techniques will continue to play a role in advancing crop varieties and hybrids better adapted to a biotic and biotic stresses, as well as producing plants that can contribute to the reduction of greenhouse gas emissions by increasing nitrogen and CO_2 input-use efficiency. "Traits that may not have been as attractive 10, 15 or 20 years ago are more important today because with these new techniques, breeders are able to look at what's in their library and although they maybe couldn't tease out a specific trait previously, today they can," says LaVigne.

This review paper highlights some on review the state of knowledge on the impact of climate change on plant breeding for food and agriculture and to discuss the potential roles of plant breeding technology tools in adaptation to and mitigation of climate change.

Discussion

Impacts of climate change on agriculture and food

Agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce crop yields while encouraging weed, disease and pest proliferation. Changes in precipitation patterns increase the likelihood of short-term crop failures and long-term production declines. Although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security (Nelson *et al*., 2009)

Table 1: the number of unnourished people in year 2080

	1990	2020	2050	2080	Ratio 2080/1990
Developing countries	885	772	579	554	0.6
Asia, Developing	659	390	123	73	0.1
Sub-Sahara Africa	138	273	359	410	3.0
Latin America	54	53	40	23	0.4
Near East and North Africa	33	55	56	48	1.5

Source: Tubiello and Fischer, 2007

Climatic changes are predicted to have adverse impacts on food production, food quality and food security. One of the most early predictions (Tubiello and Fischer, 2007; Table 1) is that by the year 2080 the number of undernourished people will increase by 1.5 times in the Near East and North Africa and by 3 times in sub-Saharan Africa compared with 1990.

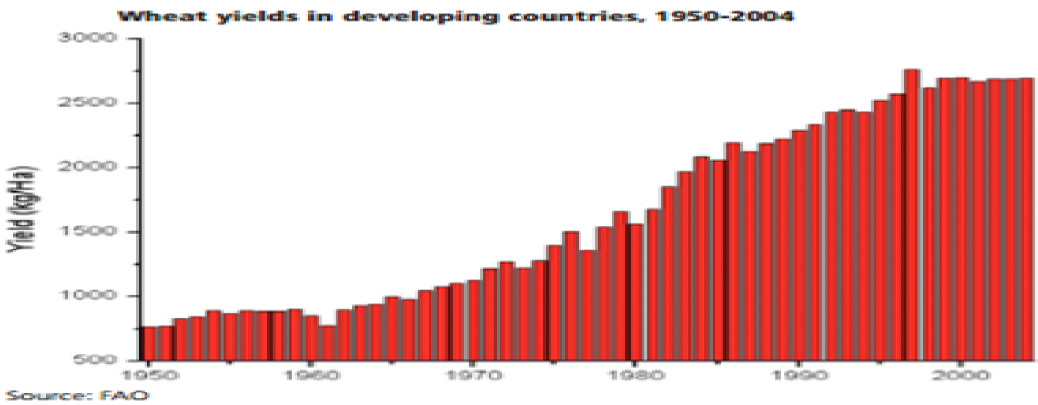
Food insecurity is likely to increase under climate change, unless early warning systems and development programs are used more effectively (Brown and Funk, 2008). Today, millions of hungry people subsist on what they produce. If climate change reduces production while populations increase, there is likely to be more hunger. Lobell *et al* (2008) showed that increasing temperatures and declining precipitation over semi-arid regions are likely to reduce yields for maize, wheat, rice, and other primary crops in the next two decades. These changes could have a substantial negative impact on global food security.

Coping with climate change role of plant breeding for food and agriculture

Numerous contributions have been made by plant breeding and over the year's plant breeders have focused on increasing the yield of varieties, on resistance to biotic stress and tolerance to a biotic stress. Other factors that have been altered for the benefit of mankind are: earliness, taste, size, nutritional and crop quality, firmness, shelf-life, plant type, labor costs and harvestability.

Yield

Arguably the most important of all characteristics is yield. Studies in different crops over many years show that yield has increased from 1 to 3 per cent per year. At first sight 1 per cent may not seem much, but when added up over many years it is a significant contribution.



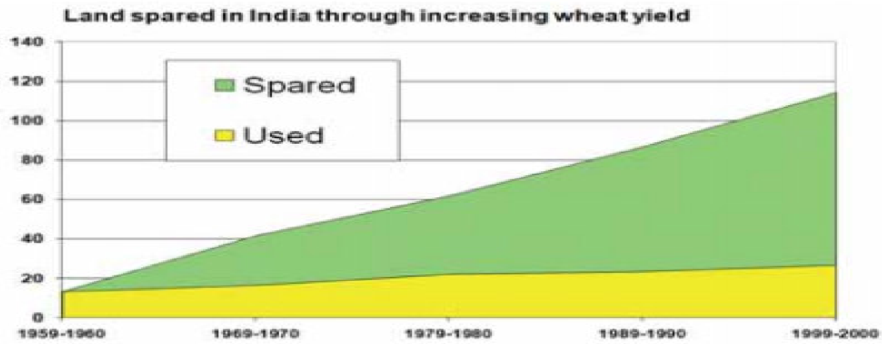
Over the past 30 years, in irrigated wheat, a yield increase of about 1 per cent per year has been achieved, which can be compared to an increase of around 100 kg per hectare per year (Pingali and Rajaram, 1999). This yield increase is not restricted to industrialized countries: FAO data for all developing countries indicate that wheat yields rose by 208 per cent from 1960 to 2000; rice yields rose 109 per cent; maize yields rose 157 per cent; potato yields rose 78 per cent; and cassava yields rose 36 percent (FAOSTAT).

Winter wheat yields in the UK have more than trebled over the past 60 years from around 2.5 tonnes/hectare in the mid-1940s to 8 tones/hectare today. To determine the effect of genetic improvements on the total yield increase, the National Institute of Agricultural Botany (NIAB) in the UK carried out a study in 2008 in which 300 varieties of wheat, barley and oats were analyzed in 3,600 trials, leading to 53,000 data points. Previous studies had already indicated that in the period 1947 to 1986 about half of the increase in yield could be attributed to plant breeding: the rest of the increase was due to improvements in fertilizer, crop protection products and machinery. The 2008 analysis revealed that in the period between 1982 and 2007 in which yields went up from 5 to 6 tonnes/hectare to 8 tonnes/hectare, over 90 per cent of all yield increase could be attributed to the introduction of new varieties. This clearly shows the contribution of the genetic component to yield increase.

Land Spared

Because yield has increased steadily over the years, plant breeders have contributed to a saving in the use of land which would otherwise have been needed to achieve the same level of production. For example: India's cereal production increased from 87 million tonnes in 1961 to 200 million tonnes in 1992 on an arable land base that has remained almost constant, and in that way has helped to limit the extension in land use. Between 1950 and 2001, the world's population grew from 2.5 billion to 5.5 billion, although the land devoted to agriculture remained stable at around 1.4 billion hectares. It has been calculated that 26 million square kilometers of land were saved and this will certainly in-crease in the future (CLI, 2001). This means that deforestation has decreased and biodiversity has been maintained.

Fig. 3 Amount of Land saved in India in Millions of Hectares in the Period 1959-2000



Source: CLI, 2001

Biotic Stress Resistance

According to FAO data, the current annual loss worldwide due to pathogens is estimated at 85 billion US dollars and to insects at 46 billion US dollars. Therefore it is not surprising that a considerable amount of effort goes into breeding for biotic stress resistance. This involves, inter alia, resistance against fungi, bacteria, nematodes, viruses, water moulds and insects. Over the years breeders have released thousands of varieties with as much or higher resistance. In that way they have given farmers the necessary harvest security to ensure that they have a crop to harvest at the end of the growing season. With this breeding for biotic stress resistance, there has been significantly less need to use crop protection products, resulting in a significant decrease in the environmental footprint made by agriculture. It has been calculated that in the UK alone, disease resistance saves 100 million pounds sterling per year on crop protection products (BSPB, 2009).

However, it should also be said that there is still a lot of work to do. For example fully resistant varieties against three fungal diseases affecting cereals and grasses, Fusarium head blight (FHB), ergot and stem rust, are still needed.

A Biotic Stress Tolerance

Ninety million people per year are affected by drought, 106 million people per year are affected by flooding and around 900 million hectares of soil are affected by salinity. In addition, according to FAO data, the current annual loss worldwide to weeds is a staggering 95 billion US dollars. Of this, around 70 billion US dollars is lost in developing countries, which is equivalent to a loss of 380 million tones of wheat. Plant breeders have also worked on tolerance to a biotic stress factors such as herbicide tolerance, drought, flooding and salinity. In the case of poor soils, breeders have attempted to select varieties which were better capable of taking up the necessary nutrients. When considering the possible effects of climate change, certain areas are expected to see a decrease in the level of rainfall, whereas other areas could expect the reverse. Plant breeders will therefore continue to research and create new genetic variations to develop the necessary germplasm to cope with these challenges.

Crop Quality

Plant breeders have adapted crops in many different ways, and here are a few examples. Brussels sprout hybrids have been developed with uniform ripening and size to make them suitable for machine harvesting; mono germ sugar beet varieties have been developed, thus reducing the need for laborious thinning and enabling fully mechanized cultivation; malting quality in barley has been improved, producing 2,000 liters of beer per ton in 1950 rising to 8,000 liters in 2008. Taste in vegetables has been greatly improved, as well as the number of health components.

The Green Revolution

This can be characterized by the combined use of high-yielding varieties, fertilizer, irrigation, machinery and crop protection products and began in 1945. In the years before the onset of the green revolution, Mexico imported half of its wheat, whereas in the mid-1950s, the country had become self-sufficient and a decade later was able to export half a million tons (Dewar, 2007). Agricultural research, extension programs and infrastructural development were also improved (Parks, 2006). In 1961, India was on the brink of famine (National Geographic Magazine, 2001), but as a result of the green revolution, India's wheat production increased from 10 million tonnes to 73 million tons between the 1960s and 2006 (BBC, 2006; CGIAR, 2007). This was accompanied by an increase in land use of only 9 million hectares (from 14 to 23 million hectares). Without the benefits of the green revolution, utilizing the best results of plant breeding, crop protection, irrigation, mechanization and education of farmers, many millions of hectares of habitat would have been plowed under (CLI, 2001).

Opportunities and challenges of plant breeding towards climate change

A few examples of the current contributions of plant breeding can be found below. They highlight the benefits of combined public and private efforts toward producing varieties with more desirable traits which will benefit mankind.

New Rice for Africa (NERICA)

The African Rice Center (WARDA) with the help of plant breeders developed new rice varieties by crossing these two types. Normally they do not interbreed so embryo rescue techniques had to be used. Upland and lowland varieties were developed showing heterosis and outperforming the best parents. One of the main features of these Nerica lines is that yield could be increased from about 1tonne/hectare to about 2.5 tonnes/hectare. With the use of fertilizer, yields of 5 tonnes/hectare were reached. The new lines have 2 per cent higher protein content, are resistant to pests and are taller than most other varieties, making them easier to harvest. Some of the newly developed lines are giving good results with relatively low amounts of water and could therefore be adapted to drought conditions (Nerica, 2009).

Tropical Sugar Beet

In an attempt to provide crops that use less water, plant breeders have developed tropical sugar beet varieties that yield the same quantity of sugar per land unit as sugar cane but use only one third to one half the amount of water. In this way, up to 10,000 cubic meters of water per hectare could be saved. An additional benefit is that these new varieties grow faster, allowing farmers to grow a second crop in the same period it would take sugar cane to mature. Therefore, in one hectare, about 10 tonnes of white sugar could be produced in five to six months instead of a year. This type of tropical sugar beet could also be cultivated on saline or alkaline soils which would otherwise be unsuitable for cane or other crops. And, last but not least, studies show that the plant removes the same amount of atmospheric carbon in half the time as does sugar cane (Syngenta, 2007).

Water Efficient Maize for Africa (WEMA)

Maize is a major staple crop but in certain areas suffers from drought which makes farming risky for millions of small-scale farmers who rely on rainfall to irrigate their crops. Plant breeders have recognized drought tolerance to be one of the most important targets of crop improvement programs. The WEMA project is a public-private partnership in which plant breeders are developing drought-tolerant maize using conventional breeding, marker-assisted breeding, and biotechnology. Combined with other efforts such as the identification of ways to mitigate the risk of drought, to stabilize yields and to encourage small-scale farmers to adopt best management practices, it will be fundamental for realizing food security and improving the livelihoods of these farmers (AATF, 2009).

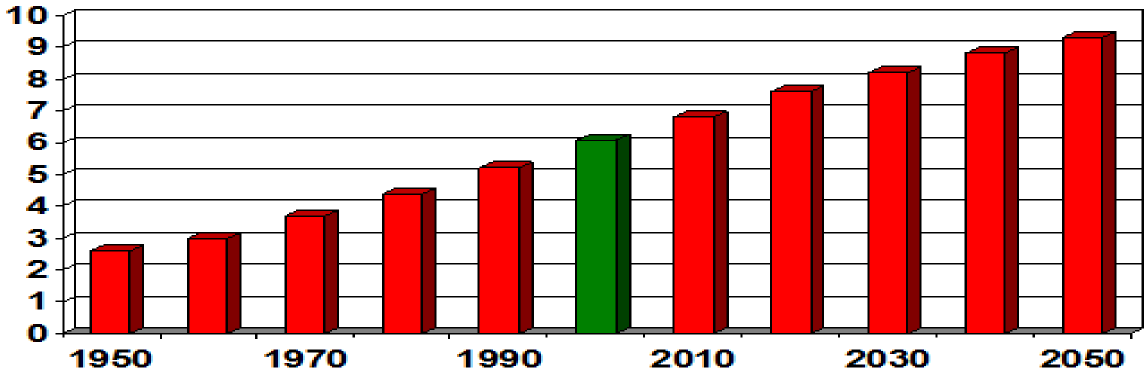
Africa Bio fortified Sorghum (ABS)

Sorghum as a crop has a high fiber content and a poor rate of digestibility of nutrients and these are major contributors to low consumer acceptance. Combined with unpredictable rainfall, declining soil fertility, inefficient production systems and biotic and a biotic stress they have caused a decline in its Production. Through the use of plant breeding, including related technologies, the ABS project endeavors to develop a more nutritious and easily digestible sorghum containing increased levels of vitamin A, iron, zinc and several essential amino acids, such as lysine. The success of the project could improve the health of 300 million people (Biosorghum, 2009)

Limitations

Human population

However more food is needed for the rapidly growing human population, food quality also needs to be improved, particularly for increased nutrient content.



Adapted from http://www.census.gov/population/popclockworld.html

In addition, agricultural inputs must be reduced, especially those of nitrogenous fertilizers, if we are to reduce environmental degradation caused by emissions of CO2 and nitrogenous compounds from agricultural processes. Furthermore, there are now concerns about our ability to increase or even sustain crop yield and quality in the face of dynamic environmental and biotic threats that will be particularly challenging in the face of rapid global environmental change.

Absence of urgent of institute measures

There is a compelling urgency to institute measures that ensure that farmers worldwide, but especially the small-scale farmers that produce the majority of the food in food insecure countries, can grow the portfolio of suitable crop varieties that are amenable to the eco-efficient production systems of the sustainable crop production intensification (SCPI) paradigm needed to feed the world in the 21st century.

Limit application of new methods

Several issues are likely to limit the application of new methods such like MAS uses a marker such as a specific phenotype, chromosomal banding, a particular DNA or RNA motif, particularly for breeding programs in the public sector. Regulatory complexity and high costs have prevented the widespread delivery of GM technologies. Over the coming decade or so, however, it seems inevitable that GM technologies will become much more widely used it is probably a case of "when, "not "if."A consequence emerging for crops that are now dominated by GM varieties (such as cotton, soybean, and maize) is that breeding programs are now based around GM varieties, and consequently, breeding programs in non-GM jurisdictions have limited access to current advances.

Lack of resources, training, and capabilities

The key limitations for traditional breeding include lack of resources, training, and capabilities for most of the world's crop improvement programs (H. C. J. God fray *et al*., 2010). It is important, therefore, that we expand the scope of and access to new marker platforms to provide efficient, cost-effective screening services to the breeders. Communication and mechanisms for delivery of material to breeders must be developed. There is an urgent need to expand the capacity of breeding programs to adopt new strategies. The clearly documented high rate of return on such investments in the past should be kept in mind (J. M. Alston *et al.* 2000). The concerns about food security and the likely impact of environmental change on food production have injected a new urgency into accelerating the rates of genetic gain in breeding programs. Further technological developments are essential, and a major challenge will be to also ensure that the technological advances already achieved are effectively deployed.

Conclusion

Plant breeding efforts to help producers overcome the enormous challenges posed by climate change through the creation of new seed varieties with improved genetics from germplasm exhibiting stress tolerance. Advances in technology have put many more tools into breeders' hands to overcome impact of climate change on Agriculture. Agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce crop yields while encouraging weed, disease and pest proliferation. Changes in precipitation patterns increase the likelihood of short-term crop failures and long-term production declines. Numerous contributions have been made by plant breeding and over the year's plant breeders have focused on increasing the yield of varieties, on resistance to biotic stress and tolerance to a biotic stress. However, more food is needed for the rapidly growing human population. A 70% increase in food production is required over the next four decades to feed an ever-increasing population. Therefore, to arrest and reverse the worrisome trend of declining capacities for crop improvement, a new generation of plant breeders must also be trained. Equally important, winning partnerships, including public-private sector synergies, are needed for 21st century plant breeding to bear fruits. The adoption of the continuum approach to the management of plant genetic resources for food and agriculture as means to improved cohesion of the components of its value chain.

Recommendation

To feed the several billion people living on this planet, the production of high-quality food must increase with reduced inputs, but this accomplishment will be particularly challenging in the face of global environmental change. Plant breeders need to focus on traits with the greatest potential to increase yield. Hence, new technologies must be developed to accelerate breeding through improving genotyping and phenotyping methods and by increasing the available genetic diversity in breeding germplasm. The most gain will come from delivering these technologies in developing countries, but the technologies will have to be economically accessible and readily disseminated. Crop improvement through breeding brings immense value relative to investment and offers an effective approach to improving food security and agriculture.

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