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Applications of Biotechnological Tools to Overcome Climate Change and its Effects on Agriculture

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Abstract

Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. Beyond its direct effects on weather, climate change will increase both abiotic stresses, such as drought, and biotic stresses, such as pest pressure, on agricultural systems. Due to emerging consequences of climate change, and the existing problems on food scarcity and food quality, new technologies like conventional and modern biotechnology can be employed to address climate change adaptation and mitigation for improved crops adaptability, productivity and food security. This review will highlight the current challenges and future perspectives of biotechnology for climate change adaptation and mitigation.

Keywords: Adaptation, Climate Change, Genetic transformation, Molecular breeding

Introduction

Climate change is one of the largest threats to agriculture in near future. It's most obvious effects would be on temperature, precipitation, insect pests and pathogens, weeds, soil quality/erosion and water quality/quantity. Agricultural activities also do contribute to global warming such as about 25% of greenhouse gas emissions, 14% of CO_2 emission and it's a major source of methane (CH_4) (48%) and nitrous oxide (N_2O), (52%) from rice fields. Implementing sustainable agricultural practices is therefore important. Biotechnological tools can be used to engineer crops that will enable farmers to use of less fuel consumption during farm operations and to practice reduced or no tillage during their farm operations. Over the period 1996 to 2005 the cumulative permanent reduction in fuel use is estimated at 4,613 million kg of carbon dioxide (arising from reduced fuel use of 1,679 million litres). The adoption of reduced tillage or no tillage systems in respect of fuel use results in reductions of CO_2 emissions of 89.44 kg/ha and 40.43 kg/ha, respectively. Therefore there is a need for the growing scientific population to find new technological solutions to cope with these challenges with technical understanding.

Biotechnological interventions on climate change

The conventional agricultural biotechnology methods which include energy-efficient farming, use of biofertilizers, tissue culture and breeding for adaptive varieties may contribute to carbon sequestration initiatives. On the other hand, the adoption of modern biotechnology through the use of genetically modified stress-tolerant, and high-yielding transgenic crops also can address the negative effects of climate change. Biotechnology can help in two different aspects like in mitigation of climate change effects and crop adaptation.

Mitigation of climate change effects through energy efficient farming

Green biotechnology offers a solution to decrease green house gases and therefore mitigates climate change. Biotech crops for the last 16 years of commercialization have been contributing to the reduction of CO_2 emissions. They allow farmers to use less and environmental friendly energy and fertilizer, and practice soil carbon sequestration. Production of biofuels, both from traditional and GMO crops such as sugarcane, oilseed, rapeseed, and jatropha will help to reduce the adverse effects of CO_2 emission by the transport sector (Sarin et al., 2007; Treasury, 2009). Green energy programs through plantations of perennial non edible oil-seed producing plants will help in cleansing the atmosphere and production of biodiesel for direct use in the energy sector, or in blending biofuels with fossil fuels in certain proportions thereby minimizing use of fossil fuels to some extent (Lua et al., 2009; Jain and Sharma, 2010; Lybbert and Summer, 2010). Herbicide tolerant biotech crops such as soybean and canola facilitate zero or no-till, which significantly reduces the loss of soil carbon (carbon sequestration) and CO_2 emissions, reduce fuel use, and significantly reduce soil erosion. Organic farming technologies utilizing bio-based fertilizers (composted humus and animal manure), or crop rotation and intercropping with leguminous plants with nitrogen-fixing abilities are some of the conventional biotechnological options for reducing artificial fertilizer use.

Biotechnology for crop adaptation

Climate change poses an enormous challenge in terms of available agricultural land and fresh water use. The agricultural sector uses about 70% of the available fresh water and this is likely to increase as temperature rises (Brookes and Barfoot, 2008). Moreover, about 25 million acres of land is lost each year due to salinity caused by unsustainable irrigation (Wang et al., 2003). With the availability of whole genome sequences of plants, physical maps, genetics and functional genomics tools, integrated approaches using molecular breeding and genetic engineering offer new opportunities for improving stress resistance (Manavalan et al., 2009).

Molecular breeding for stress resistance

Although some progress has been made through conventional breeding (Blum, 1985), breeding for abiotic stress tolerance is difficult due to the complex nature of abiotic stress tolerance (timing, duration, intensity, frequency) and thereby its quantification and repeatability; because undesirable genes are also transferred along with desirable traits; and because reproductive barriers limit the transfer of favorable alleles from diverse genetic resources. Advances in genomics coupled with bioinformatics and stress biology can provide useful genes or alleles for conferring stress tolerance. Superior genes or alleles where they have been identified in the same species can be transferred into elite genotypes through molecular breeding. Moreover, by using an approach such as genetic engineering, there is no barrier to transferring useful genes or alleles across different species from the animal or plant kingdoms. Crops tolerant to various abiotic stresses have been developed in response to climatic changes.

Genetic engineering for abiotic stress tolerance

In Australia, field trials of 1,161 lines of genetically modified (GM) wheat and 1,179 lines of GM barley modified to contain one of 35 genes obtained from wheat, barley, maize, thale cress, moss or yeasts are in progress since 2010 and will run till 2015. Some of the genes are expected to enhance tolerance to a range of abiotic stresses including drought, cold, salt and low phosphorous. Sugarcane that contains transcription factor (*OsDREB1A*) is also under field trial from 2009 to 2015 (Tammisola, 2010). More than a dozen of other genes influencing salt tolerance having been found in various plants, some of these candidate genes may prove feasible in developing salt tolerance in sugarcane, rice, barley, wheat (Wang, 2003), tomato (Moghaieb et al., 2011), and soybean. Structural genes (key enzymes for osmolyte biosynthesis, such as proline, glycine/betaine, mannitol and trehalose, redox proteins and detoxifying enzymes, stress-induced LEA proteins) and regulatory genes, including dehydration–responsive, element-binding (DREB) factors, zinc finger proteins, and NAC transcription factor genes, are being used. Transgenic crops carrying different drought tolerant genes are being developed in rice, wheat, maize, sugarcane, tobacco, *Arabidopsis*, groundnut, tomato, potato and papaya. Marker-free transgenic wheat using a transcription factor, *AtDREB1A* has been developed against moisture stress tolerance (Kasirajan et al., 2014). Expression of heat shock proteins (HSPs) has been associated with recovery of plants under heat stress and sometimes, even during drought. HSPs bind and stabilize proteins that have become denatured during stress conditions, and provide protection to prevent protein aggregation. In GM chrysanthemum containing the *DREB1A* gene from *Arabidopsis thaliana,* the transgene and other heat responsive genes such as the HSP70 (heat shock proteins) were highly expressed when exposed to heat treatment. The transgenic plants maintained higher photosynthetic capacity and elevated levels of photosynthesis-related enzymes. Recently, a gene encoding aquaporin (*NtAQP1*) was identified in tobacco (*Nicotiana tabacum*) and shown to provide protection against salinity stress in transgenic tomatoes (*Solanum lycopersicum*) (Hu et al., 2006). *NtAQP1* plays a key role in preventing root/shoot hydraulic failure, enhancing water use efficiency and thereby improving salt tolerance.

Conclusion

Plant biotechnology can contribute positively towards climate change adaptation and mitigation through reduction of CO2 emissions, carbon sequestration, reduced fuel use, adoption of environmentally friendly fuels, and reduced artificial fertilizer use, employing biofuels for improved soil fertility and crop adaptability. These measures are meant to improve agricultural productivity and food security, and at the same time protecting our environment from adverse effects of climate change. Improved crops resilient to extreme environments caused by climate change are expected in a few years to a decade. Hence, food production during this era should be given another boost to sustain food supply for the doubling population. An integrated approach to safe applications of both conventional and modern agricultural biotechnologies will contribute to increased yield, food security and also it will also significantly contribute to climate change adaptation and mitigation initiatives.

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