Education Pack

Plant Biotechnology - A Solution for Africa

Voice Over Transcription - Discussion Text

1. Crop Production in Africa

The production of crops in Africa has always been difficult; the environment is harsh and frequently unpredictable. Farmers have been regularly facing poor yields and crop losses due to drought, pests and diseases, but now the impact of global warming is making crop production even more unreliable than ever before. Climate affects crop growth not only by determining the length of the growing season, but also by affecting soil structure and the prevalence of pests and diseases, Temperature, rainfall and the amount of carbon dioxide in the atmosphere also affect crop yield dramatically. Even at the same site, and with the same plant variety, yields may differ by as much as 100% from year to year as a result of environmental variability.

To combat this new set of challenges, arable farmers will need new improved crops that are capable of growing well under different, probably more variable temperatures and rainfall. In the years to come we can expect to see big changes in the countryside. Some types of farming will become easier and others harder as the climate changes and in some areas familiar landscapes could look quite different, as new crops will be grown for fuel or valuable compounds alongside those grown for food.

2. Use of Biotechnology in crop plants

Scientists are working to develop new crops, which will be better suited to extreme or variable climates, so that agricultural land will remain productive during periods of drought or extreme temperatures. A common approach to this research is to learn how plants have evolved to cope with very extreme climates, and to use this information to introduce these characteristics into crops, to make them what we call "hardy".

Plants that live naturally under conditions of extreme environmental stress may provide clues about traits that can help crops to survive in environments that experience drought and high or very low temperatures. Discovering how plants survive stressful environmental conditions helps us to predict how plants will respond to climate change, and what this will mean for natural and farmed environments.

Biotechnology is one important technology that is helping to develop essential new crop improvement strategies. It is also helping to develop renewable sources that do not increase carbon emissions.

3 What is Plant Biotechnology and what techniques do we use?

Biotechnology is defined as the use of plants, microorganisms or biological substances, such as enzymes, to perform specific industrial or manufacturing processes. Applications include the production of certain drugs, synthetic hormones, and bulk foodstuffs. Biotechnology also allows us to gain a deeper scientific knowledge and understanding of the fundamental biological processes that operate in living organisms. Here, we discuss some to the ways in which Plant Biotechnology is being used to gain new knowledge and understand how plants survive stressful environmental conditions, with a view to developing improved breeding tools for selection of useful traits such as drought tolerance. Plant Biotechnology includes a variety of plant science disciplines and is based increasingly on understanding the genetic programs that make plants work as they do.

To understand the biological programs that control plant functions and important agronomic traits, we have first to identify the basic components or "genes" that are involved. In this way we study fundamental processes that regulate the life of plants. For example, once scientists have identified the genes that equip plants to tolerate and continue to grow under extreme climates, they can begin to select varieties that express similar genes in a commercial crops. We can now test the role and function of many genes through the techniques of modern Biotechnology. Molecular biology allows us to isolate, extract and amplify any gene that we want and to track the activity of these genes in different plants of the plant. A wide range of techniques are used to characterize gene regulation and function.

Then we can apply a number of techniques if we want to modify plants through biotechnology. The technique of genetic transformation allows genes to be inserted into or silenced in plants to study what effects they have. The technique of plant tissue culture allows us to propagate and regenerate whole plants with desirable traits, e.g. virus free lines of bananas. In addition, we can introduce new or modified genes into plant cells and regenerate new lines following genetic transformation. Alternatively, by a process called "marker assisted breeding" we can find desirable traits in a wild relative of crop plants and introduce these traits into commercial varieties using either conventional breeding tools or plant transformation..

Plant Biotechnology has played a major role in revealing the genetic make-up of plants, which is amazingly similar across different species. The complete set of genes or "the genome" of a small plant called Arabidopsis is particularly useful. It is relatively simple and acts like a 'blueprint' for finding comparable genes in more complex plants.

Using Arabidopsis and other 'model' species, researchers have identified individual genes, and combinations of genes, that determine how plants respond to their environment. Individual genes or groups of genes influence traits such as plant shape, the time of flowering, responses to temperature, and the ability to resist disease. This knowledge gives crop breeders a 'toolkit' for mixing and matching varieties to suit different environmental conditions.
We can then use this information to test how such genes function in crops such as wheat, maize and rice. Sometimes, we can introduce key genes that we need by conventional strategies of plant breeding, perhaps by introducing the desired trait (e.g. disease resistance) from a wild relative of a crop species. We can also directly insert genes into crops by genetic transformation and then look for altered growth and/or stress tolerance characteristics.

4. Growth of maize (corn) at high carbon dioxide-photosynthesis

Carbon dioxide is a 'greenhouse gas' that drives global warming. We know that the amount of carbon dioxide in the atmosphere has increased dramatically in the past 200 years. If it continues to increase as it is today it could be several times higher in the next century. However, we do not know how these high carbon dioxide levels will alter the growth and productivity of major crops like corn.

Corn yields are currently adversely affected by drought and chilling and the effects of these stresses are predicted to increase due to climate change. Like all plants, corn uses photosynthesis to convert light energy into chemical energy that turns carbon dioxide into sugars. However, plants like maize already have a carbon dioxide pump that enriches the gas in the leaf cells making photosynthesis much more efficient.

Scientists are using the genes that encode the carbon dioxide pump proteins to transform other crop species such as wheat (that do not have this pump) to see if this will allow them produce more grain and be more efficient. However, it could be that carbon dioxide-pumping plants such as maize will suffer negative affects growing in the carbon-dioxide rich world of the future, so it is important that we should test this out now. By growing plants in an atmosphere with high carbon dioxide, we can see how they grow, and how the underlying gene programs control growth and crop productivity.

5. Legume crops and the stability of nodule nitrogen fixation

Another key target for biotechnology is the group of plants that we call "legumes". Legumes are one of the world's most important sources for vegetable protein, oil and secondary metabolites. They are also a crucial reservoir of natural nitrogen fertilization in agriculture. This is because legume roots produce highly specialized structures called "nodules" that house nitrogen-fixing bacteria in a symbiotic association. Adding nitrogen fertilizers to soils to increase crop yields is not only expensive but it is a main source of CO_2 emissions. So making the best possible use of natural legume fertilizers is very important.

Legumes such as soybean, chickpeas and cowpeas are important legume food and feed crop in Africa. Understanding the relationships between the legume plants and the nitrogen-fixing bacteria is important for improving plant nitrogen gain and crop quality particularly in poor soils. The symbiotic nodule is highly sensitive to environmental conditions and it breaks down upon exposure to stresses such as water-deprivation and heat. Legume crop production can therefore be severely restricted because of early nodule senescence and death brought about by even short periods of drought or high temperature.

Scientists are searching for the plant genes that trigger the roots of legumes to form nodules in which the nitrogen-fixing bacteria live. We also look for genes that keep the symbiosis going, even during extreme stress. In the longer term transferring the properties required for biological nitrogen fixation to non-legume crops such as cereals could dramatically reduce reliance on nitrogen fertilizers for resource-poor farmers.

Scientists are working to establish strategies for the improvement of legumes such as soybeans so that they perform close to their theoretical maximum yields over a wider the range of environmental conditions, particularly in situations of limiting water and high temperatures. In order to do this we have to define the mechanisms by which environmental stress induces premature nodule senescence and terminates symbiosis. Our aim is to identify the different genes expressed during leaf and nodule senescence and characterize their functions, with a view to using them in future plant-breeding programs.

We identify senescence-related gene expression in legumes under stress using transcriptome analysis. The transcriptome is basically a catalogue telling us how much each gene in the plant is working at a given moment in time. Micro-arrays are tiny grids carrying samples of thousands of different genes from a single plant species. The allow us to monitor how each of these genes is working in a particular plant tissue.

The long-term goal is to identify genes that are induced during stress so that we can use them as markers and targets for manipulation by genetic transformation or marker-assisted breeding. An example of the type of useful genes that we might use to improve nodule stability is a set of genes encoding natural components that prevent specific proteins from being broken down. These natural inhibitors are called plant cystatins or "phytocystatins". When expressed at high levels in plants, they prevent stress-induced senescence. We therefore wish to study whether nodule senescence can be prevented or delayed by over-expression or by silencing the natural phytocystatins. If there is an effect does this change the plants ability to survive under conditions of environmental stress?

Under even mild environmental stress, plant cells may stop dividing, and so the plant stops growing. Research on the regulation of cell division is revealing how this response works. We can study the co-ordination of defense, growth and development in plants using a range of tools. For example, we have been studying how stress-induced changes result in changes in tissue levels of vitamin C, and how this influences cell division and the cell cycle. We use metabolite profiling and metabolomics to monitor the content and composition of different low molecular weight compounds in cells in culture and in plant tissues. Similarly, we can use gel electrophoresis and proteomics to study how plant proteins are changed by stress.

6. Learning more about Plant Biotechnology

Scientists across the world are working together not only improve crops to meet future needs but also to build capacity for Plant Biotechnology research in Africa. You can learn how to use Biotechnology tools in the laboratory, in classes at your university, or even high school.
The knowledge of how to use plant biotechnology is open to everyone, and the skills we have described in this video can be easily learnt. The studies described above are being implemented in a joint project by scientists from the University of Pretoria, the University of Limpopo and CSIR in South Africa, Rothamsted Research and the University of Newcastle upon Tyne in the UK, and Case Western Reserve University in the USA. If you want to know more about the LEGIM project or want to get involved in Plant Biotechnology, please log into
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