Biotechnology optimizes yield in crops

Green fitness program

In the course of evolution, plants have faced and overcome many challenges, but ensuring a good harvest isn't one of them. Using biotechnological methods, researchers at Bayer CropScience intend to lend a helping hand and optimize crop yields in the agricultural industry.

Increasing crop yield is a major goal for the plant industry to ensure the food supply for a growing population and increase potential industrial uses for plants that are currently being studied. Yield can be affected by various stress conditions. For instance, spring 2007 was a nightmare for many farmers in Europe: a heat wave and inadequate rainfall took its toll on all kinds of crops. The question as to whether these conditions are a direct effect of climate change is a matter of speculation at present. What is certain, however, is that even farmers in temperate climate zones now need to impose new demands on their seed. Modern crops need to yield more and more than before. They need to resist extended dry periods, weather floods and withstand drastic temperature fluctuations and intense sunlight.

In the process of evolution, it wasn't critical for the survival of a plant species if individuals succumbed to temporary stress or bore little fruit in a given season. Most plants are made for "average" weather conditions. In other words, their ability to adapt to brief periods of stress is less than perfect. In addition the basic yield capacity of plants may not have been optimal. Today, however, a team of biologists at Bayer CropScience's Innovation Center for Plant Biotechnology in Ghent, Belgium, are working on changing that. "We had been exploring the general idea of getting crops into better shape," says Michael Metzlaff, Head of the Crop Productivity Research working group. What they developed is a program for increasing crop yield either directly or indirectly by enhancing the resistance of plants to stress using biotechnological means. Initially, the program will focus on a model plant, known as thale or mouse-ear cress (Arabidopsis), as well as on rapeseed, rice and cotton crops.

Targeted silencing of the stress gene

Working together with renowned partners, Metzlaff's team is pursuing two strategies: first, to insert a useful gene in the test plants that enhances their yield or ability to withstand excessive stress due to drought or wetness; second, to suppress specific, individual genes that negatively affect yield or that would trigger an exaggerated stress reaction in

High harvest yields: Michael Metzlaff (left) inspects rapeseed crops that have been made more resistant to stress by means of targeted gene silencing. His colleagues at Bayer CropScience's research center in Ghent are working on optimizing other crops such as cotton (right) and rice.

Resistant to stress: Bieke Nagels checks the growth progress of rapeseed plants. As part of the breeding process, she also manually pollinates other crops such as cotton (right).

the original plant. However, Metzlaff is not in search of maximum yield. What's more important, he says, "is the right mix of several favorable characteristics. No one needs plants that only produce record harvests and that require an immense investment in terms of time and expense." The goal of the Bayer scientists is consistency: "We want to enable plants to achieve high, stable yields over long periods of time despite fluctuating environmental conditions."

Optimized photosynthesis ensures better use of energy

One promising result of a collaborative project was published recently in the leading science journal Nature Biotechnology: a team headed by Christoph Peterhänsel, a biotechnologist at Aachen University of Technology, succeeded in integrating five genes from the Escherichia Coli bacterium into the thale cress genome. Thanks to these genes, which also occur in blue-green algae, the plant supplies its chloroplasts with three new enzymes. These organelles are the site where photosynthesis takes place, the process by which plants turn sunlight into energy. In doing so, the plants consume carbon dioxide and give off oxygen, but the reaction is not very efficient. "A plant usually throws away about one-eighth of the carbon dioxide previously bound in its system," Peterhänsel explains, "which is nothing but a waste of energy." In the modified plant, photosynthesis works more efficiently and one-third of the carbon dioxide otherwise wasted is now reused. "Recycling saves the plant a lot of energy," Peterhänsel says. "As a result, the genetically modified plants grow faster, produce more biomass and store up more energy."

The researchers now want to use the method on commercial crops. If the process proves successful in these plants as well, it could ensure higher yields.

Another important part of the program is the increase in the ability of plants to cope with various environmental stresses. Metzlaff explains: "In view of the rising demand for food all over the world, combined with the increasing significance of plants as raw materials, for example in the production of biodiesel, it is becoming more important to access new land." Stress-resistant plants can make this vision a reality. For instance, rapeseed that tolerates freezing temperatures could be planted by Canadian farmers 14 days earlier and thus achieve good crop yields. This would help to safeguard harvest yields despite the short vegetation period in Canada. With a rice variety capable of growing on salty soil, over-farmed fields would be useable again. And when plants can survive a day under water, new farmland could even been found in flood regions.

One approach is to engineer plants in such a way as to conserve the levels of the energy carrier NADH, particularly under stressful conditions. "These plants are real energy savers, and preliminary experiments with Arabidopsis have shown that they are more stress-tolerant," Metzlaff says.

Gene silencing increases rapeseed yield by up to 40 percent

The question as to whether the new technology also enhances the stress tolerance of modified crops is soon to be answered in field trials. Already, the third major project of the team headed by Michael Metzlaff indicates that the field trials may well lead to successful results: genetically modified rapeseed has been growing on Canadian experimental plots since 2005. When the researchers exposed it to an artificial drought, the harvest was 40 percent higher than with conventional rapeseed. If these figures are confirmed in genetically modified, high-yield rapeseed varieties and other crops, the method could soon be developed for market introduction.

So what did the researchers actually do with the rapeseed? They used an innovative key technology, known

Stress under film: in the Ghent greenhouse, rice plants are exposed to artificially extreme environmental conditions.

Results made visible by light: UV light is used to make visible DNA fragments of rapeseed varieties that have been reproduced by means of polymerase chain reaction (PCR). This makes it possible to predict the oil composition of the analyzed plants.

as "gene silencing". With this method, the researchers suppress the activity of specific genes by incorporating gene fragments containing the code for the matching, mirror-image fragments. These mirror images block the RNA messenger molecules that transport genetic information to the sites where new proteins are produced. As a result, the cell produces significantly less of a specific substance than it actually intends to produce. The use of such RNA-blocking mirror images, also referred to as RNA interference (see also page 38, "Good detective work") was first described in roundworms by two U.S. researchers who received the Nobel Prize in medicine in 2006.

With this technology, the Bayer CropScience biologists managed to suppress the activity of the PARP gene – which is activated when the plant is under stress (see also *research* 16, "Braving the drought") – to about half its normal level. "This gene is a central switching station for the stress reaction," Metzlaff explains. "Once it's switched on, it influences the activity of hundreds of other genes." This dramatic metabolic change is a plant's reaction to non-favorable conditions. But what sounds so positive is the root of the problem: the plants overshoot their target and their reaction is too extreme. By silencing PARP, the researchers found a happy middle ground which permits a moderate reaction to stress, but prevents overkill.

"Hopefully, in about ten years, we will be in a position to modify a plant in several ways at the same time," Metzlaff says. "Once we reach that stage, we'll have such extensive control of the methods we're working on now that we can combine them in any number of ways, like Lego bricks." Only then will the biologist in Ghent have reached their ultimate goal: to find the perfect mix of favorable characteristics and put together an ideal yield and fitness program for each crop plant.

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Green lungs

The Global Vegetation Index produced by NASA shows the annual average distribution of the green zones on our planet – the darker green the area, the more green foliage is produced by plants, which serves as an indicator of the photosynthesis activity in the region in question. Higher photosynthesis rates mean that the plants there "breathe" in more carbon dioxide, thus supplying the Earth with oxygen. The yellow zones symbolize real desert areas which could perhaps soon become greener thanks to the plant optimization technologies developed by Bayer scientists.