Workshop B2 – Science and technology assessment – Case studies

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Case study: Transgenic drought- and salt-tolerant plants

Summary and supplement of the Gentechnik-Nachrichten Spezial 15, „Transgene dürre- und salztolerante Pflanzen“, Öko-Institut eV., Germany Feb. 2004 (www.oeko.de)
An often heard argument for agro biotechnology is: "With genetic engineering we can create salt- and drought resistent plants. This could be an enormous help for the South."

False promises or real hopes?

A desk study from the ‚Ökoinstitiut Freiburg' (Germany) looked into this issue.
Most plants are sensitive to salt and water deficit. There are exceptions, however, that are able to withstand extreme abiotic stress situations. In the course of evolution these plants have developed various adaptive strategies, such as:

Drought-resistence: Plants have deep root systems; their superterranean parts are covered by a thin layer of wax called cuticle; they keep their stomata closed during the day to avoid evaporation; they reduce transpiration by dropping off leaves at the beginning of a drought season; they retain water in specific water-tissues, etc. (Strasburger 2002; Nultsch,2001)

Salt-resistence: Plants with a high salt tolerance can increase the salt NaCl uptake in the cell sap, thereby creating a balance between the in- and outside. A few are able to segregate the sodium and chloride ions of salt through specialized glands on their leaf surface.
All of these strategies are based on a great number of genes and complex regulatory mechanisms, on an intricate balance of genes, proteins and other molecules. (Lewis 2002)

Recent research on transgenic drought- and salt- tolerant plants

Stress tolerance in plants (be it to water deficiency or higher amounts of salt) generally occurs by way of interaction of a whole network of different genes. Most of the research so far has focussed on single components of this complex trait:

Osmoprotectants: Osmoprotectants are compatible solutes such as proline (amino acids), glycine betaine and sugars (mannitol, fructans, trehalose) that function as osmolytes and protect cells from dehydration by turgor maintenance of roots and shoots in response to water deficit. Several studies have shown that transgenic plants with an osmoprotectant-producing gene have an increased drought- and salt tolerance. (Yamaguchi-Shinozaki et al 2002; Datta 2002; Hanson 1998; Wu&Garg 2003)

Protection factors of macromolecules: LEA-proteins (late embryogenesis abundant proteins) and chaperones (heat-stress induced proteins) have been shown to protect macromolecules such as enzymes, lipids and mRNAs from dehydration. The introduction of the LEA protein gene HVA1 from barley into rice led to second generation transgenic rice plants with a significantly increased tolerance to water deficit and salinity. (Xu et al 1996; Datta 2002)

Membrane proteins: Channel proteins and other transporters in cell membranes regulate the osmotic pressure in plant cells. Eduardo Blumwal's studies on a transport protein called

AtNHX1 showed that in tomatoes the latter is located in the membranes of cell vacuoles where it protects the plant from the drying effect of salt by transporting sodium ions from the cell cytoplasm into the vascuole. An overexpression of the AtNHX1 gene resulted in an enhanced salt tolerance in the tomatoes. Fruit sodium content of the genetically modified tomatoes was low because the plants store the sodium in the leaves' vacuoles. (Xu et al 1996; Datta 2002)

Detoxification enzymes: High temperatures or water deficit lead to the production of toxic reactive oxygen combinations, causing extensive cellular damage and inhibition of photosynthesis. This phenomenon is known as oxidative stress. Different enzymes help in eliminating these toxins. At the University of Bonn researchers have found a gene that encodes the production of a detoxification enzyme. Genetically engineered cotton plants containing the oxidative stress-related gene for the production of the enzyme ascorbate peroxidase (APX) have been tested in field trials. Transgenic plants showed increased production. (Moffat 2002)

Transcription factors: Transcription factors play a role in DNA regulation. Research on the genomes of tomato plants has led to the identification of ca 20 genes that encode heat stress transcription factors. This means that the reaction of plants to harmful environmental influences is based on an extremely fine regulatory system. (Wandtner 2002)

Recent research on drought- and salt-tolerant plants – without genetic engineering

Worldwide, many different so called farmers' varieties show a high tolerance to adverse environmental conditions such as water deficit or saline soil. There is a huge genetic diversity of traditional crop plants with these properties, developed over hundreds of years by the indigenous farmers, and now considered as their cultural inheritance.
During the last decade, new breeding methods have led to enormous progress on the new-plant-variety front. Researchers have successfully combined molecular marker technology, which allows a more precise identification of strains carrying specific traits, with traditional plant breeding. This has helped improve the development of new plant varieties without the use of genetic engineering.

Examples:

The small Indian state of West Bengal alone grows 78 varieties of rice that are suited for dry conditions. Salt-tolerant rice varieties can be found throughout India. By drawing up a **variety-register**, the Indian Research Foundation for Science, Technology and Natural Resource Policy has shown how many drought- and salt-tolerant rice varieties still exist, despite agricultural intensifications and the Green Revolution. (Mishra 2002)

In **screening Thailand's seed bank**, a collection of 7,000 indigenous rice varieties, scientists at the National Centre for Genetic Engineering in Bangkok discovered 4 varieties that survived watering with salt water that contained 2-3% sodium chloride. These 4 rice varieties have been selected for further testing. (Gentechnik-Nachrichten 30, Oeko-Institut)
In 2001, South Africa's Ministry of Agriculture released a **new maize variety (ZM521)** which produces yields up to 50% higher than those of traditional varieties under drought conditions. **ZM521 is commercially available**.

In Australia, a new variety of **highly water-efficient wheat**, called Drysdale semi-dwarf, was developed without genetic engineering and is capable of increasing grain yields by up to

10% in drought-affected areas. Drysdale has a high resistance to all major wheat diseases and produces a high quality grain. **It is also commercially available**.

In India, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has introduced **short-duration chickpea varieties**, which mature in 85-100 days, and thereby escape the yearly end-of-season drought.

Pre-exposition: Various studies have shown that plants can survive in normally lethal salt concentrations and drought situations when their roots are subjected to similar circumstances from the beginning on. These plants learn to cope with less favourable conditions (Zhong & Dvorak 1995; Amzallag et al 1990).

Conclusions

Drought- and salt-tolerance are complex phenomenons in plants, involving many different genes. Whether transgenic plants will ultimately contribute to the struggle against world hunger, is questionable due to monocausal beginnings. Transgenic plants with a drought- and salt-tolerance have been developed but they are not (yet) cultivable. Most test results are based on greenhouse experiments. Very few field trials have been done with transgenic breeds. There are no commercially available varieties.

Traditional plant breeding relies on existing genetic variability, and scientists maintain that it is difficult to modify single traits (Holmberg & Bülow 1998). However, through intensive breeding efforts over hundreds of years, many different varieties have been developed that show the desired traits in regionally adapted farmers' crops. The latter are in harmony with the local environment and its ecology. New drought- and salt-tolerant varieties are already on the market.

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