UNIVERSITÄT HOHENHEIM

Food and Nutrition Security of the World: The Role of Biotechnology

Honoring the 80th Anniversary of

Ehrensenator

Dr. Dr. h.c. Hermann Eiselen

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May 10-11, 2006

Program

10.05.2006 Aula (Schloss-Mittelbau)

Opening Remarks

Chair: Prof. Dr. Gerd Weber

13:00	Prof. Dr. Hans-Peter Liebig, Rektor, Universität Hohenheim Prof. Dr. Peter Frankenberg, Minister für Wissenschaft, Forschung und Kunst, Baden-Württemberg

Scientific Presentations

	Introduction to the Program *Gerd Weber, (convener) Kompetenzzentrum Pflanzenzüchtung, Forschungs-schwerpunkt Biotechnologie u. Pflanzenzüchtung, Universität Hohenheim*
14:00 - 14:35	Biotechnology to fight hunger-vision or reality? *Wilhelm Gruissem, ETH Zürich, Switzerland*
14:35 - 15:10	The Hohenheim Research Center of Biotechnology and Plant Breeding: Highlights from two decades (1985 – 2005) *Hartwig H. Geiger, Universität Hohenheim, Germany*
15:10 - 15:45	Molecular approaches for improving water-stress tolerance of cereals and legumes in the semi-arid tropics *David Hoisington, ICRISAT, India*
15:45 - 16:15	*Coffee Break*
	Chair: Albrecht E. Melchinger
16:15 -16:50	New genetic variation for wheat improvement in developing countries *Susanne Dreisigacker, CIMMYT, Mexico*
16:50 - 17:25	Stress tolerant maize making a difference to African farmers *Marianne Bänziger, CIMMYT, Kenya*
17:25 - 18:00	Can biotechnology straighten the bent future of bananas? *Laszlo Sagi, Katholieke Universiteit Leuven, Belgium*

Balkonsaal / Grosses Foyer (Schloss-Mittelbau)

19:00	Opening of the buffet *Prof. Dr. Hans-Peter Liebig*
	Dinner speach *Prof. Dr. h. c. Adolf Martin Steiner*
	Dinner

11.05.2006 Aula (Schloss-Mittelbau)

08:15 *Chair: Matin Qaim*

08:30 - 09:05 Biological and economic impact of the release of an exotic diamondback moth parasitoid *Diadegma semiclausum* (Hym. Ichneumonidae) in Kenya
Bernhard Löhr, ICIPE, Kenya

09:05 - 09:40 Compatibility of insect-resistant transgenic plants with biological control
Jörg Romeis, Agroscope FAL Reckenholz, Switzerland

09:40 - 10:15 ProVitaMinRice: Preventing multiple micronutrient deficiencies using biofortification
Jorge Mayer, Universität Freiburg, Germany

10:15 - 10:45 *Coffee Break*

Chair: Franz Heidhues

10:45 - 11:20 Economic Impacts of Genetically Modified Crops in Developing Countries
Matin Qaim, Universität Hohenheim, Germany

11:20 - 11:55 Ensuring safe use of GMOs in developing countries: The Cartagena Protocol on Biosafety
Hans-Jörg Buhk, BA f. Verbraucherschutz und Lebensmittelsicherheit, Berlin

11:55 - 12:30 La Recherche--Du Temps Perdu? Successes and Continuing Challenges in Addressing Global Hunger and Malnutrition
Patrick Webb, Tufts University, Boston, USA

Concluding Remarks

12:30 *Prof. Dr. h. c. Franz Heidhues*
Dr. Dr. h .c. Hermann Eiselen
Prof. Dr. Gerd Weber

13:00 End of colloquium

Scientific Presentations

Biotechnology to fight hunger – vision or reality?

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When the Swiss politician Jean Ziegler, who is the UN representative for the 'Right for Food', publicly stated that "every child, who died from starvation, was murdered", many thought he was again provocative (http://www.g26.ch/texte_jean_ziegler_00.html). But his statement is probably not far from the truth. Presently we might have sufficient food to feed the world population, but it is uncertain if current food production can be sustained in the future. This uncertainty causes serious concerns and challenges scientists to explore biotechnology as a new method to improve crop yield and quality, and even consider crop plants to produce pharmaceuticals more cost effectively.

Is hunger unavoidable?

What does 'Right for Food' or 'Food Safety' mean in our society? It means that everybody has access to food on a regular basis, in sufficient quantity, and of good quality. The FAO estimates, however that every day about 800-900 million people worldwide go to bed not just hungry, but starving. And perhaps more than two billion people are malnourished (1). Why then is Jean Ziegler probably right? The U.S. alone, for example, is home to about 70 million cats and 60 million dogs (http://www.apapets.com/petstats2.htm). And depending on the choice of website, this number may even be higher (http://www.hsus.org). If one estimates the daily feed for these animals (200 g meat for each cat and 500 g meat for each dog), this alone results in 44,000 metric tons of meat every day. Considering that it requires about the 10-fold weight of grain equivalent to produce meat from plants, this amount of grain equivalent would be sufficient to feed 1.1 billion people at an average Italian food standard, which corresponds to 400 grain equivalents per day. This calculation does not include European pets or any of the small or exotic animals that we keep for human amusement. Even if one excludes from this calculation brave pets that chase mice or guide blind people, for example, still nobody in this world would have to starve. Biotechnology can contribute very little to this dimension of hunger, because the reasons for the hunger of 800-900 Million people are–among others–found in politics, culture, and narrow-minded thinking of those who are well fed.

Agricultural constraints to fighting hunger

Many NGOs argue that hunger is only the result of the unequal food distribution. While this may be true to some extent, food donations can only be a short-term solution to prevent starvation. Ethical consideration preclude simply supplying food from rich to poor countries, because such distribution makes beggars out of people who are in need. As a matter of human dignity and sustainable solution to hunger, even poor countries must be able to feed their own population. The International Food Policy Research Institute proposed a bold plan to reach sustainable food security by 2020 (2), but recently had to retract on this goal already. In many developing countries it is difficult to produce sufficient food because fertile soils are lacking and the climate is arid. Soils in the tropics and subtropics are often low in phosphorus and nitrogen. Dry and hot periods are frequent, and irrigated land is threatened by salinization. Warm climates support insect and pathogen survival, thus exposing crops to high disease and pest pressures that are detrimental to efficient crop production and seed storage. Furthermore, the lack of food diversity threatens human health, which can only be averted by fortification of staple crops with vitamins and trace elements. Many of the problems discussed above can be approached through breeding programs. But even this approach is often constrained by the lack of suitable breeding material, because appropriate genes were either lost during several thousand years of cultivation or do not exist even in related wild type species.

The role of biotechnology in improving agricultural production

Although plant biotechnology alone cannot solve all problems in agriculture and human nutrition, it provides new tools for crop production that are critically needed to feed the current and future world population (3). Biotechnology has the potential to exploit useful genes from any species to engineer suitable genotypes of crop plants that are more resistant to diseases and abiotic stress such as salt or drought. Crops that have been improved using biotechnology provide new breeding material for important traits.

Looking into the future, we face additional problems: even if all birth control programs that have been launched would be successful (which, as we know, they are not because many religious groups do not support governmental efforts), the world population will continue to increase to at least 9 or even 12 billion people within the next 50 years. At the same time, useful agricultural land is lost to erosion or construction of streets and buildings (4). According to estimates of the United Nations, this loss of agricultural land during the last 40 years has reduced farmed land from about 0.45ha per capita in the 1960's to about 0.25ha per capita in 2005. More importantly, this irreversible loss of agricultural land occurs in temperate climates where high crop yields are possible. Especially in the industrial countries construction is using up some of the best agricultural land at the size of soccer fields every day (e.g., in Germany). Consequently, in order to feed the growing human population crop yields per acre must be nearly doubled in the next decades to compensate for the loss of agricultural land.

Crop yields have been improved significantly during the past 70 years, but only to some extent by breeding of novel varieties. Most of the yield increase is the result of fertilization and spraying chemicals against diseases and pests. Although chemical application is currently the most effective solution to increase yield, it is energy-intensive and environmentally not sustainable. Although unknown to much of the public, European agriculture subsidies are paying for the energy that is needed to sustain high crop yields (up to 10 metric tons per ha of wheat in central Europe). Even if Europe could afford to pay high agricultural subsidies and costs for energy-intensive crop production in the future, oil supplies as the source of chemical inputs into agriculture are dwindling. Phosphorus is already scarce now because guano islands have been nearly depleted. Nevertheless, European agriculture continues to deploy much of the fertilizer phosphate and nitrogen into rivers, lakes and oceans.

Future agriculture must use production systems that are highly efficient and that minimize chemical inputs. Crop yields reduced by pests or rotting during storage translate into lost fertilizer, land and energy that could have been used more effectively. Equipping crop plants with genetic resistance to diseases, genes for nitrogen assimilation, and genes for increased efficacy of photosynthesis might help to reduce chemical and energy input into agriculture while maintaining maximum crop yield. Classical breeding alone cannot achieve these improvements, because no "natural" genes are available in the gene pools of crop species for many of the desired traits. Biotechnology can offer the tools and has the potential to develop new traits by genetic engineering, thereby complementing conventional breeding efforts (5). Using appropriate stewardship, in the last ten years genetically modified plants have already contributed to sustainable agricultural production while benefiting the environment and farmers (6). In the following we will discuss our biotechnology research to improve cassava as an example how genetic engineering can complement conventional breeding practices to improve food security and reduce hunger.

Cassava – a little known crop that feeds millions of people

Although unknown to many Europeans, cassava (*Manihot esculenta* Crantz) is an important crop not only for farmers and agro-industry producers in the tropics, but especially for subsistence farmers in Sub-Saharan Africa. Cassava is a 1-5 m high woody, perennial shrub that produces starchy tuberous roots and belongs to the spurge family (*Euphorbiaceae*). Cassava is native to tropical South America, but today it is cultivated worldwide in more that 80 countries between 30° north and south. Both its leaves and starchy storage roots are eaten as food, while the stem is typically cut into small segments to grow new plants. This vegetatively propagated root crop provides food for 600 million people worldwide and serves as raw material for industrial production of animal feed, starch, and bio-ethanol. In Sub-Sahara Africa, for example, more than 200 million people rely on cassava as a daily staple food for caloric energy, carbohydrate, and fiber. In 2005, global cassava production reached 203.9 million tonnes harvested from more than 18.6 million hectares, of which more than 68% is located in Africa where food insecurity continues to be an immense problem.

Constraints of cassava production

Because of its drought and low soil fertility tolerance as well as hardiness, cassava can grow under marginal environmental conditions and in areas where few other crops can sustain competitive yields. Cassava is therefore fundamental to subsistence farming, food security and bio-energy. Several constraints, however, have reduced the interests of agro-industries and farmers from further exploring cassava production and usage. In Africa, reliable cassava production is strongly impacted by whitefly-transmitted diseases caused by African cassava mosaic Gemini viruses (CMGs) and cassava brown streak viruses. Cassava storage roots are full of starch, but they lack sufficient protein (less than 1%) and are also very susceptible to stresses common in the areas and conditions where it grows. After harvest, cassava storage roots undergo fast post-harvest physiological deterioration (PPD) and within 72 h, they are not longer marketable. Several reports also indicate that greater leaf longevity, especially under drought conditions, could be important for increasing yields and/or the stability of production in cassava, as well as improve the access to an important nutrient source. Due to the biological nature of cassava, including the vegetative propagation mode, high heterozygosity, as well as low fertility and seed setting, conventional breeding efforts to address the constraints to cassava production have only met with limited success. Biotechnology provides the necessary tools to make cassava much more productive, a better source of nutrients, and profitable to grow, thereby greatly contributing to the sustainable development of tropical agriculture.

Cassava – a case study of biotechnology-assisted crop improvement

Our cassava group is a key member of the BioCassava Plus Consortium (http://biocassavaplus.org/), whose goal is to improve food security and the health of Africans through delivery of novel cassava germplasm using transformation and biotechnology. To achieve our goals, a prerequisite is the development of an efficient cassava transformation protocol for delivery and stable expression of genes of interest. Our group has established genotype-independent gene transfer techniques for cassava using *Agrobacterium tumefaciences* and particle bombardment (7-9). These protocols have been transferred to several laboratories in developing countries. Recently, we also identified two cassava storage root-specific promoters, which can be used to regulate gene expression in cassava storage roots (10).

Genetic engineering of virus-resistant cassava lines

Cassava mosaic diseases are caused by Gemini viruses and threaten the production of the crop in large parts of central Africa. Cassava mosaic Gemini viruses (CMV) have two genetic components transmitted as twinned icosahedral particles. They cause mosaic symptoms in infected cassava leaves and reduce plant growth and storage root production. Infection of cassava with severe virus strains can result in the complete failure of root production. Development of CMV-resistant cassava using conventional breeding has been met with only limited success. To tackle the problem caused by CMVs, such as Africa cassava mosaic viruses (ACMV), we developed RNA-mediated tools to engineer resistance against cassava Gemini viruses in transgenic cassava. The first approach involves expression of viral antisense-RNAs to inhibit virus replication and accumulation in cassava plants. Viral replication assays in detached leaves indicated that replication of ACMV isolates was strongly reduced or inhibited in some transgenic lines (11). Upon ACMV infection of complete plants by biolistic-inoculation, several antisense-RNA lines remained completely symptom-less at lower infection pressure. In most lines, symptom development was delayed and attenuated even at higher viral DNA doses (12). Viral DNA accumulation was significantly reduced in infected leaves of these transgenic plants. Following ACMV challenge, short interfering RNAs (siRNAs) specific to the transgenes were identified in the tested transgenic cassava lines, demonstrating that the genetic engineering of virus-resistant cassava was effective (13).

Our second approach focuses on RNA interference (RNAi)-mediated Gemini virus resistance in transgenic cassava. RNAi is a conserved silencing mechanism that regulates mRNA accumulation by post-transcriptional and/or transcriptional gene silencing. The specificity of this RNA regulation is based on homologous short double-stranded interfering RNAs (siRNA). Transgenic cassava expressing hairpin double-stranded RNA (dsRNA) homologous to viral DNA sequences are expected to reduce viral mRNA production, thereby decreasing virus replication and movement in the infected plant. We therefore considered highly conserved DNA sequences amongst Gemini virus species as the best targets for RNAi-based resistance. Cassava plants engineered to express specific RNAi constructs showed reduced viral DNA replication and fast recovery from infection. Therefore, both antisense-RNA and RNAi strategies produced ACMV-resistant cassava, which demonstrates that biotechnology tools are effective for problems that are otherwise difficult to solve..

Improving the nutritional quality of cassava storage roots

Cassava roots contain starch up to 85% of their dry weight, but are virtually devoid of storage protein (only 1% of total protein mass). This can lead to severe qualitative malnutrition in areas of Africa where the diet is based mainly on cassava. Introduction of high-value storage protein genes into cassava roots would therefore improve the nutrient balance and quality. We transformed ASP1, an artificial storage protein similar to maize endosperm storage proteins but optimized for high essential amino acid content, into cassava (14). To optimize protein expression and accumulation, we have fused the protein to different cellular organelle targeting signal sequences. Transgenic cassava lines with increased protein content will also be tested for its viability in the field as well as efficacy in humans. Once suitable transgenic lines with high protein content have been identified, they can provide a more balanced diet to people who dependent on cassava as a staple crop.

Genetic engineering of cassava leaf longevity

Cassava leaves are not only a factory for photosynthesis, but also serve as a nutritious vegetable. However, cassava leaves have a very shoot life span. Extending the life span of cassava leaves could result in higher root yield, improved root quality, and more frequent leaf harvesting. We explored the expression of the cytokinin biosynthesis enzyme isopentenyl transferase (ipt) under the control of the senescence-induced Arabidopsis SAG12 promoter to interfere with the onset of leaf senescence. Transgenic plants showed a significant stay-green phenotype and repressed chlorophyll degradation after dark-induced senescence treatment of mature leaves. During their development, transgenic plants retained a high chlorophyll content as well as high protein levels, which are normally reduced in mature leaves. As the result, the transgenic plants also showed an early storage root bulking in comparison to wild-type plants. Transgenic plants also showed resistance to leaf senescence after drought treatment. Evaluation of the transgenic plants for leaf and storage root yields, as well as drought resistance, is currently underway in field trials.

Plant biotechnology–a field of opportunities

The approaches discussed above establish an important proof-of-principle that quality and yield improvement of cassava is feasible by controlled expression of candidate genes in transgenic plants. Like the cassava biotechnology research described here, many important strategies for crop improvement are already being pursued by public research institutions in developing countries. But there are also large impediments to the success of these local projects as a result of public apprehension to biotechnology approaches in food production and of slowness in developing a suitable regulatory environment. The General Assembly of the United Nations approved a call in 2003 (15) that 'Urges the relevant bodies of the United Nations engaged in biotechnology to work cooperatively so as to ensure that countries receive sound scientific information and practical advice to enable them to take advantage of these technologies, as appropriate, to promote economic growth and development.' Anything else would be a crime against humanity and fighting hunger—and a waste or opportunities offered by plant biotechnology.

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The Hohenheim Research Center of Biotechnology and Plant Breeding: Highlights from two decades (1985 - 2005)

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The Research Center of Biotechnology and Plant Breeding (in short Research Center) of the University of Hohenheim was established in 1985. This became possible by a generous long-term capital endowment granted by the "Vater und Sohn Eiselen Stiftung Ulm" (in short Eiselen Foundation). The aim of the Eiselen Foundation was and still is to support research devoted to reduce hunger and malnutrition in the developing countries. Accordingly, an interdisciplinary research project "Applied Genetics to the Benefit of Word Food Supply" (Angewandte Genetik im Dienst der Welternährung) was set up by Hohenheim plant breeders, geneticists, physiologists, pathologists, and seed scientists comprising a broad spectrum of interconnected sub-projects attempting to develop new tools and base material for the improvement of yield, quality, disease and pest resistance, and stress tolerance of major crop plants. In 1986, the Eiselen project was flanked and strengthened by a cooperative project granted by the former German Federal Ministry of Research and Technology (BMFT) to speed up the integration of knowledge and know-how from cell and molecular biology into classical breeding procedures. The two projects expired in 1996 and 1995, respectively. In total, the financial support provided by the Eiselen Foundation amounted to about 6 Mill. EUR and the BMFT grants to 5 Mill. EUR.

After this starting phase, the program of the Research Center became more diversified with regard to both, objectives and donors. Most projects were, or still are, involved in cooperative national or European research programs such as the BMFT program Biotechnology 2000, the BMBF (Federal Ministry of Education and Research) funded German Plant Genone Program GABI, the French-German EUREKA Program CEREQUAL, the 6th EU Framework Program, and the DFG (German Science Foundation) Priority Program Heterosis in Plants. Substantial funding has also been received from the State of Baden-Württemberg (Ministerium für Ernährung und Ländlichen Raum) for research in plant genetic engineering.

Past and present projects of the Research Center can be assigned to the subsequent areas. Selected keywords referring to crop species and project objectives are given in brackets:

- *In vitro* techniques (ryegrass, triticale; screening for disease resistance and stress tolerance)
- Haploid induction (maize, barley, rye; *in vitro* and *in vivo* approaches; breeding for stress tolerance)
- Gene technology (wheat, paprika, hop, apple; protein quality, disease resistance, micro-nutrient concentration)
- Molecular population genetics (maize, wheat, barley, rye, ryegrass, various legumes, various fungal pathogens; genetic diversity, population structure, migrations, mating systems, linkage disequilibrium)
- QTL mapping (maize, rye, sorghum, sunflower; genetic and physical mapping; yield, quality, disease and pest resistance, male fertility restoration)
- Marker assisted selection (maize, wheat; chilling tolerance, nitrogen efficiency, disease resistance)
- Genome analysis (maize, barley; chilling tolerance, nitrogen efficiency, plant development, grain protein and starch content)
- Molecular basis of heterosis (maize, *Arabidopsis thaliana*; differential gene expression, allelic and non-allelic gene interaction, overdominance)
- Breeding informatics (linking information from molecular genetics and applied breeding)

Results of the research activities have been presented at annual status seminars and published in a large number (several hundred) of papers, dissertations, posters and lectures. Here I would like to briefly highlight a few of the results to illustrate the scientific impact of the past research activities.

- ***In vivo* haploid induction in maize.**

  This technology is an attractive alternative to *in vitro* methods like anther or microspore culture as used in other crops. It is based on the ability of specific 'inducer' genotypes to furnish a certain percentage of haploid offspring when used as pollinator parent. In the lab of H.H. Geiger nine years of research resulted in (i) an inducer line (RWS) with superior induction ability and a dominant grain colour marker for separating haploid from regular F_1 embryos and (ii) a highly effective chromosome doubling protocol allowing to produce large populations of doubled haploid lines from practically every donor genotype. The technology is meanwhile extensively being used in research and breeding and is rapidly substituting the classical line development by continued selfing.

- **Indirect gene transfer in wheat**

  Several years before the establishment of the Resarch Center, D. Heß and co-workers had shown that isolated DNA could be transferred into an eggcell using pollen as a vector. This fascinating result had been accomplished in the model plant petunia. In the Research Center, the group attempted to apply the technology to wheat in order to increase protein quality and disease resistence. After many failures, the alien DNA could eventually be detected in first-generation transformants but no gene expression was observed. Disappointed the group switched to Agrobacterium tumefaciens as a vector and greatly contributed to carrying forward the Agrobacterium-mediated gene transfer from dicot to monocot plants.

- **QTL mapping**

  The Research Center belonged to the first institutions focussing on the identification and mapping of quantitative trait loci (QTL) in field crops. A.E. Melchinger's group established large mapping populations of maize and evaluated them for various yield and disease resistance traits. Molecular markers of the RFLP type were used to generate genetic maps and to determine the position of QTL on these maps. For the latter purpose a specific software (PLAPQTL) was developed by H.F. Utz. It has become one of the most widely used computer program in this field internationally. Finally, G. Weber's group, using sophisticated *in situ* hybridization techniques, determined the physical distance between flanking markers of important QTL and revealed large discrepancies between physical and genetic map distances. Results demonstrated that physical maps are indispensable for isolating genes segregating at QTL in maize.

- **Marker analysis of host-pathogen population systems**

  In a plant pathosystem, the population structure of the pathogen depends on that of the host and *vice versa.* DNA markers are excellent tools to analyze this interaction. In the Research Center two comprehensive projects were dealing with this problem. The team of H.G. Welz mapped QTL for quantitative resistance of tropical maize to Northern Corn Leaf Blight (NCLB) and determined the genetic diversity in various local pathogen populations as well as in a world collection of single spore isolates. Results showed that under the environmental conditions of Kenya only polygenic resistance can withstand the pathogen and that none of the known hypersensitivity-type resistances provide effective protection. The great adaptability of the pathogen to new resistances was in agreement with the abundant marker diversity in local pathogen populations and with a remarkable migration potential. Similar findings were obtained by T. Miedaner's team in analyzing the wheat-*Fusarium graminearum* pathosystem. His team went one step further and mapped QTL for aggressiveness of the pathogen. Interestingly, the genetic basis of aggressiveness largely corresponds to that of resistance on the host side. These findings are of utmost conceptual importance in breeding for durable resistance.

- **Genomics of chilling tolerance in maize**
  Since 2000, the Research Center is involved in the federal genomics program GABI. The first project, GABI Cool, has been dealing with chilling tolerance in maize. Being indigenous to the tropics, maize may be strongly affected by cool temperatures in early spring and late autumn. In Central Europe breeding for tolerance to 'chilly' conditions is an important breeding goal. The GABI Cool project detected and mapped various QTL for chilling tolerance and verified the efficacy of the most important QTL by marker-assisted selection and by evaluating near-isogenic lines. RNA profiling and databank retrieval generated putative candidate genes for the trait. Several of these genes mapped within QTL intervals. Present studies are focusing on isolating and characterizing the QTL-associated genes. The project is a good example of progress achievable by tight collaboration between complementary scientific disciplines (P. Westhoff, Düsseldorf: molecular biology; H.H. Geiger, Hohenheim: population and quantitative genetics) and between academia and seed industry (KWS SAAT AG, Einbeck).

For the sake of brevity it was not possible here to list all past and present projects of the Research Center and the scientists and partners from outside who were involved in the work. For more information, the reader is referred to the reports of activity presented at the annual status seminars of the Research Center and to a collection of summaries of all sub-projects funded by the Eiselen Stiftung during 1985 to 1996. Copies are available from the Research Center.

In conclusion, the Research Center can look back to many important, internationally well recognized scientific achievements. The initial focus on problems of developing countries has been maintained in many research groups. Interdisciplinary cooperation, within the University of Hohenheim and with partners from outside, has steadily gained in importance. The research topics refer to key issues of modern agricultural biology. Close links exist between the Research Center and the recently established Hohenheim Life Science Center.

Molecular approaches for improving water-stress tolerance of cereals and legumes in the semi-arid tropics

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The semi-arid tropics (SAT) covers parts of 55 developing countries where the crop growing period has a mean daily temperature of more than 20 degrees Celsius. The SAT is home to over 1.4 billion people of which 560 million (40%) are classified as poor, and 70% of the poor reside in rural areas. Various abiotic stresses are responsible for yield loss, instability and poor quality of many crops grown by resource poor farmers in the semi-arid tropics environments. Drought alone is globally the most important constraint to crop productivity. With climate change and predictions of increased water scarcity in the future, water-stress is likely to remain the number one constraint. As irrigation is often not available in the SAT, especially for resource poor farmers, it is critical that genetic enhancement focus on maximizing the extraction of available soil moisture and improving the efficiency of water use in crop establishment, growth and yield.

Genetic improvement of drought tolerance is a challenge for conventional breeding approaches that rely on selection for yield in drought-stressed environments. The large genotype by environment interaction for yield and the difficulties of controlling the level of water stress under natural conditions makes direct selection for yield ineffective. Thus, the application of biotechnology provides approaches for improving component traits of drought tolerance that should prove more effective and efficient than the conventional selection methods.

At the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), a major breeding objective is to develop chickpea, groundnut, pigeonpea, pearl millet and sorghum varieties that are resilient under low and erratic rainfall conditions. Towards this goal, scientists are investigating a number of traits associated with improved water uptake and water use efficiency, have screened a wide range of genetic resources for variation in key component traits for drought tolerance, developed molecular maps for genes involved and used marker-assisted selection to introgress these into locally-adapted cultivars. In addition, genetic engineering is being used to introduce novel genetic variation for specific genes believed to be involved in the abiotic tolerance pathways/mechanisms.

In pearl millet, several putative Quantitative Trait Loci (QTLs) were mapped for grain and stover yield under terminal drought stress. Nineteen near-isogenic lines (NILs) for one major QTL on linkage group 2 (LG2) were developed. Testcross hybrids of these NILs and their two parents (donor PRLT 2/89-33 and recurrent parent H 77/833-2) were evaluated for agronomic performance across fourteen managed and natural terminal drought stress environments in India. Across all environments, testcross hybrids of the introgression lines ICMR 01029 and ICMR 01031 performed substantially better than those of the recurrent parent H 77/833-2 for grain yield. These results validate the previously identified QTL on LG2 of PRLT 2/89-33 for grain yield under terminal drought.

Stay-green or delayed foliar senescence is a secondary trait used in selection for terminal drought tolerance in sorghum. Stay-green is a post-flowering response that is expressed when plants are under severe stress during grain filling. Tolerance is indicated when plants remain green and fill grain normally. The sorghum breeding line B35 is the best-characterized source of the stay-green component of post-flowering drought tolerance, and several putative QTLs for the stay-green trait from B35 have been identified in several published studies based on four different mapping populations.

ICRISAT has initiated SSR marker-assisted backcrossing programs to transfer gene blocks governing the stay-green trait from donor parents B35 and E 36-1 to a range of elite tropically-adapted sorghum cultivars currently grown and preferred by resource-poor farmers in the tropics of Asia, Africa and/or Latin America. Among the recurrent parents for which crossing programs have been initiated are included ICRISAT-bred improved open-pollinated varieties S35 (released in Ghana as ‘Kapaala’, where this is by far the most popular improved sorghum variety; also released and popular in Chad and Cameroon) and Macia (released in Kenya and elsewhere in Eastern and Southern Africa), ISIAP Dorado (originally released in El Salvador and Mexico, and now cultivated from Paraguay to Egypt), and short-duration open-pollinated variety IRAT 204).

In chickpea, efforts are being made to exploit root traits that allow extraction of soil moisture from deeper soil layers under receding soil moisture conditions. The drought tolerant genotype

ICC 4958 was found to have 30% higher root biomass than the popular variety Annigeri. Over 250 RILs were developed from the cross of ICC 4958 x Annigeri and a major QTL was identified that accounts for about one-third of the variation for root dry weight as well as root length. Two new mapping populations, developed using parents having greater differences for root traits, based on the screening of the ICRISAT mini-core collection of chickpea are being used to map additional QTLs.

Besides improved deep and profuse roots for water mining, high water use efficiency is another essential component for improved yield under water deficit. Groundnut genotypes with higher transpiration efficiency (TE, in g of biomass per kg of water transpired) were identified and mapping populations involving contrasting parents for TE developed. These are now being phenotyped. The identification of molecular markers linked to putative genes controlling TE and several surrogate traits (specific leaf area, specific leaf nitrogen, SPAD chlorophyll meter reading, and $\Delta^{13}C$) is in progress.

Finally, we are exploring the possibility to use genetic engineering of groundnut to improve traits such as TE. The transcription factor *DREB1A* under the control of the stress-inducible *rd29A* promoter, both isolated from *Arabidopsis thaliana*, was introduced into the peanut variety, JL 24, through *Agrobacterium tumifaciens* mediated gene transfer. *DREB1A* regulates gene expression via recognition of the DRE (Dehydration Responsive Element) sequence. Over 50 transgenic events were produced and advanced to the T3 generation. Several transgenic lines in the T3 generation have been evaluated in the greenhouse using a dry-down protocol to simulate field stress conditions. Parameters studied included the fraction of transpirable soil water (FTSW)-threshold, transpiration efficiency (TE), chlorophyll content (SCMR), specific leaf area (SLA), specific leaf nitrogen (SLN), and carbon isotope discrimination ($^{\Delta}C13$) under dry-down and well-watered conditions. Many of the transgenic events maintained higher TE and biomass than the untransformed controls under drought stress conditions. A consistent negative correlation of SLA and positive correlation of SCMR with TE was observed. FTSW-threshold was negatively correlated with TE thus suggesting that the transgenic plants delayed stomatal closure.

Drought is a complex phenomenon and we believe it will require a multi-faceted approach, including tools from modern biotechnology, to develop the improved varieties required by resource-poor farmers living in arid and semi-arid areas. Mini-core collections (10% of core collection, 1% of entire collection), representing species diversity of chickpea and groundnut have been useful in identifying genetically diverse germplasm lines for use in breeding programs to develop broad based drought tolerant cultivars. Our efforts to date have indicated that molecular markers can be used successfully to introgress genomic regions controlling traits involved in better performance under drought. Genetic engineering also holds promise for even a complex trait such as tolerance to drought. It is especially useful for providing important insights into how particular genes respond to and are involved in a plant's response to water deficit.

New genetic variation for wheat improvement in developing countries

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Wheat is the principal ingredient in everything from Ethiopian flat breads and Indian chapattis to French baguettes and American doughnuts. In recent years, planted area of wheat worldwide has dropped as it loses ground to other crops, particularly corn. Domestic food use of wheat has also declined as a result of changing consumer preferences and improved bread preservation technology. Nevertheless, wheat is the main source of food for two billion people and unless serious action is taken, drastic crop losses from climate change, drought, and disease may soon become the norm.

Drought tolerance, water use efficiency, and resistance to several biotic stresses are high priority traits in the CIMMYT global wheat program. Drought severely limits wheat productivity in many environments around the world. Some estimates indicate that 50% of the world's annual wheat area is regularly affected by drought (Pfeiffer et al., 2005). Breeders have made significant progress in developing wheat cultivars better adapted to moisture limited conditions. Improvements in wheat productivity globally of 1-2% per annum have been reported (Troyer, 1999), and it is recognized that improved agronomic techniques account for a considerable portion of this. However, actualizing the benefits of improved farming practices is frequently dependent upon the availability of suitable or responsive cultivars.
One indispensable tool for the genetic improvement of crop cultivars is to broaden the breeders' current elite gene pools with new genetic variation. Genetic gain from improvement cannot be achieved in the absence of genetic variation, and elite materials often exhibit limited diversity in comparison to the variability within the species and its wild relatives worldwide. Wheat is a hexaploid and typically has six copies of each gene. It is derived from two relatively recent polyploidization events between three clearly identified diploid species. The first event, between *Triticum monococcum* and (putatively) *Aegilops speltoides*, occurred about 500,000 years ago and led to the appearance of tetraploid hard wheat (*Triticum dicoccoides*). The second polyploidization event took place about 9,000 years ago, between hard wheat and a third diploid, *Triticum tauschii*. Polyploidization events probably occurred only a few times, perhaps only once.

Therefore, it is expected that wheat underwent a severe genetic bottleneck during domestication, meaning that only a very small number of individual plants within each of the three grass species contributed diversity to what later became the staff of life in many countries (Dvorak et al., 1998). Modern plant breeding may also have unintentionally diminished genetic variation. Only the best genotypes are selected in a breeding program; farmers, commodity handlers, processors, and consumers demand uniformity. This, in turn, leads to the development of genetically homogeneous cultivars, and as a result, a few widely adapted varieties are promoted over large growing areas.

Germplasm from landraces and wild relatives represent unique sources of new genetic variation for improvement that is absent in elite materials. Fortunately, hundreds of thousands of seed samples from plant genetic resources have been collected over the last century and stored in national and international gene banks. The Wellhausen-Anderson Genetic Resources Center at CIMMYT maintains the largest collection of wheat genetic resources in the world, consisting of more than 160,000 accessions of cultivars, landraces, and wild relatives. CIMMYT, therefore, holds a key position in conserving the genetic diversity of wheat and in making it available for breeding.

Determining which of the thousands of ex-situ accessions contain useful new genetic variation is often difficult. It is not feasible to screen every gene bank accession for all traits. Furthermore, many of the old varieties and wild species possess agronomic deficiencies and poor adaptation to target environments. At CIMMYT, large-scale screenings of subsets of wheat gene bank accessions are only performed for specific purposes. Selection criteria can thus be clearly delineated and subsets of wheat accessions can be defined by knowledge management. The screening is followed by the introgression or incorporation of the detected desired trait via backcrossing into elite materials. New resistance for the barley yellow dwarf virus (*Aegilops gemiculata*), Karnal bunt (*Tritiucm tausschii*), Russian wheat aphid (*Triticum diccocum*), leaf rust (*Triticum durum*), and yellow rust (triticale) have been identified in this manner.

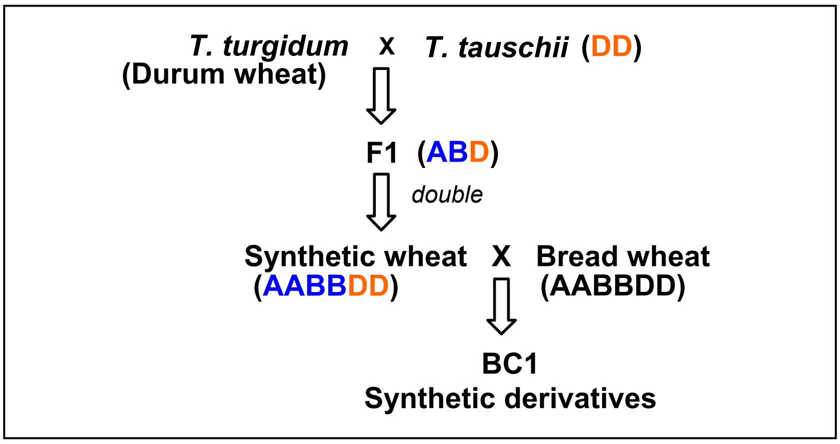

Fig.1. Scheme of the creation of synthetic and synthetic derived wheat.

The creation of synthetic wheats at CIMMYT is an innovative and very effective approach for introducing new genetic variation from wild relatives into elite gene pools. Synthetic wheats are produced by artificially crossing tetraploid forms such as modern durum wheat, donor of the A and B wheat genomes, with *Triticum tauschii*, donor of the D genome (Fig.1). The resulting hybrid is haploid and carries the A, B, and D genomes (Mujeeb-Kazi et al., 1996). It is converted to a true hexaploid by using artificial chromosome doubling methods and can then easily be crossed with improved varieties. The resulting synthetic derived wheats are improved varieties that also have desirable traits from the wild parents. More than a thousand synthetic wheats have been produced from more than 600 *Triticum tauschii* accessions at CIMMYT since the early 1990s. CIMMYT has produced synthetic wheats and their derivatives with traits such as resistance to septoria and fusarium head blight, and tolerance to drought, heat, salt, or water logging (Cox et al., 1998 for review). The impact of synthetic derived wheats is illustrated by the fact that in 2005 more than 50% of the wheat lines sent from CIMMYT to over 100 collaborators in 50 countries for field trials in International Bread Wheat Screening Nurseries were lines derived from synthetic wheats.

Measurements of molecular and functional diversity utilizing molecular marker technologies can enhance the use plant genetic resources. In gene banks they can help us determine the distribution of genetic variation, to tag redundant germplasm, and to quantify genetic drift within accessions.

They can additionally assist to sample or validate the assembly of generic core collections that capture most of the genetic variability in the entire collection and are unbiased for any morphological or agronomic trait. Molecular diversity studies identify genetically similar or distinct accessions and determine individual degrees of heterozyosity and heterogeneity within sets of plant genetic resources. With the financial support of the Vater & Sohn Eiselen Foundation, CIMMYT observed that the new diversity for many specific traits observed in synthetic wheats in the field is also evident at the molecular level. Applying microsatellite markers confirmed that the synthetic wheats form an entirely different pool of genetic variation and thus represent a very interesting source for broadening the genetic base of elite gene pools for certain traits (Zhang et al., 2005).
The new variation was inherited by CIMMYT wheat lines that were backcrossed to the synthetics, thereby moving this variation into the elite breeding pool. The new synthetic derived wheat germplasm has had a positive effect on the overall diversity levels of CIMMYT wheats (Warburton et al., 2006). The diversity in these recent CIMMYT breeding lines is the highest it has been in 50 years and has reached levels that are comparable to those in landraces. It was also observed that the new diversity found in the synthetic wheats was sometimes preferentially inherited, indicating the effect of positive selection on the chromosomal regions under consideration. Consequently, fingerprinting (with molecular markers) the synthetics, the CIMMYT wheat lines, and the lines derived from crossing the two, followed by testing for selective advantage of synthetic over improved wheat variety alleles at the DNA level, is a promising method for detecting chromosomal regions of interest for wheat improvement.

In recent years, increased insight into molecular organization of genomes and newly available marker technologies, have promulgated methods to directly mine the allelic diversity in plant genetic resources. The aim of such functional diversity studies is to associate sequence polymorphisms within genes across genomes with phenotypic variants to detect superior alleles affecting agronomical important traits. The major advantage of these methods over classical mapping experiments that have been used to date is that no specific populations have to be established. The full allelic variation available in natural populations of gene bank accessions can thus be covered and the results are not limited to the specific populations. Additionally, several traits can be studied and a higher proportion of molecular markers are likely to be polymorphic, providing better genome coverage. One of CIMMYT's goals for the future is to apply these methods to synthetic materials, with a special emphasis on drought tolerance and associated traits.

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Stress tolerant maize making a difference to African farmers

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Low heritabilities, small genetic variance, and significant genotype-by-environment interactions have restricted plant breeding progress in stress-prone environments. CIMMYT introduced in the 1970s the concept of managed abiotic stress environments. Selection was conducted in tropical maize populations exposed to severe but carefully managed N stress, mid-season drought stress, or low pH stress, and selection progress approximating 100 kg ha^{-1} $year^{-1}$ was reported for performance under the target stress. So far, little has been known on the impact of such a selection approach on performance of maize in a highly variable stress-prone environment. This presentation reports on results obtained from a product-oriented breeding program initiated in 1997 and targeted at improving maize for the stress-prone mid-altitudes of eastern and southern Africa.

Maize varieties were developed in Zimbabwe using simultaneous selection in three types of environments, recommended agronomic management/high rainfall conditions, low N stress and managed drought, sampling together two abiotic (drought, N stress) and several biotic stress factors (maize streak virus, gray leaf spot, northern leaf blight, rust, and ear rots) relevant in southern and eastern Africa. Improved statistical design and analysis techniques and secondary traits were used to increase the precision of identifying desirable genotypes. Between 2000 and 2002, 41 hybrids from this stress breeding approach were compared with 42 released and prereleased private seed company hybrids, selected mostly under high potential conditions, in 36-65 trials across eastern and southern Africa. Average trial yields ranged from less than 1 t ha^{-1} to above 10 t ha^{-1}. Hybrids from CIMMYT's stress breeding program showed a consistent advantage over private company check hybrids at all yield levels. Selection differentials were largest between 1 to 3 t ha^{-1}, i.e. yield levels most relevant to smallholder farmer environments, and averaged close to 20%. They became less at yield levels above 5% but were still positive. The results show that including selection under carefully managed high priority abiotic stresses in a breeding program and with adequate weighing can significantly increase maize yields in a highly variable stress-prone environment and particularly at yield levels which are most relevant to smallholder farmers.

Stress-prone environments in low income countries also pose unique challenges to disseminating seed to farmers. Farmers have little purchasing power and, due to insecure return to investment and lack of information, buy seed of improved varieties only occasionally. Seed companies face small margins and geographically dispersed sales. In collaboration with national agricultural research programs and partners from the private and NGO sector, CIMMYT is involved in several initiatives in southern Africa that stimulate both seed supply and demand. Through these initiatives more than 45,000 tons of stress tolerant maize seed has reached farmers in Africa over the past four years.

Can biotechnology straighten the bent future of banana?

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Introduction

With an annual production of over 100 million metric tons bananas (including plantains) are the most important fruit crop on Earth and cultivated in close to 140, chiefly less developed countries in tropical and subtropical regions (Anonymous, 2005). Bananas are a staple food in the producing countries for about half a billion people and also important dessert in developed countries, which is provided by a US$ 5 billion trade market worldwide. This market is based on the more than 10% export of the annual production, which generates a significant foreign exchange for most exporting countries and thus banana industry has a major impact on their national economies. For example, banana export in Costa Rica accounted for 23% of total value of exports in 2000 whereas in the Windward Islands this value reached as much as 50%.

In this overview, the current threats to banana production are summarised followed by an outline of available biotechnological tools and a brief analysis of the application of these tools to develop strategies for a better perspective.

The bent future

A recent report in New Scientist (Pearce, 2003) presented a doom scenario for the future of banana with a fairly quick extinction on a term of 10 years, which stirred quite some controversion in the circles of the banana community and far beyond. According to this scenario, the recent emergence and fast spread of a tropical race 4 of *Fusarium oxysporum* f. sp. *cubense* in South-East Asia may result in a major disaster for the banana industry, and production on the whole, if the pathogen appeared in Latin America where most commercial plantations are located. The main reason for this concern is the lack of an alternative; no useful resistant genetic resources are known in banana germplasm collections.

However, *F. oxysporum* is only part of a more complex problem. In major production areas the leaf pathogen *Mycosphaerella fijiensis* has caused for decades a permanent threat or even epidemics, which can only be controlled by frequent spraying with fungicides, at frequencies of once a week for an extended period in extreme cases. This powerful selection pressure combined with high recombination rate during the pathogen's sexual cycle has led to frequent incidences of fungicide resistance in the field, which forces the chemical industry into a race with the pathogen. Time will only show who is going to win but one victim is certainly the environment that is loaded by other harmful compounds such as fumigation agents used against soil nematodes (*Radopholus similis*, *Pratylenchus coffeae*, *Meloidogyne incognita*).

Costa Rica is again an illustrating example: the country uses about seven to eight times more pesticide per hectare than the world's average and even more on banana plantations where the average application rate reaches as much as 30-40 kg/ha annually. Considering the total surface of plantations, which is about 45,000 ha, this is a huge amount of pesticides that is released each year.

While strict control and/or effective quarantine measures can prevent or diminish the spread of pathogens the most durable and environment-friendly solution could be the introduction of disease-resistant cultivars. At this point lies another major bottleneck; bananas are extremely difficult to breed by conventional means due to a high degree of sterility and low germination rates of the few seeds that can at all be collected after pollination. Taken together with a relatively long life cycle (1-2 years), no suprise that a bred cultivar has not hit the market on a real large scale. Therefore, generation of improved and resistant cultivars in banana will have to rely on biotechnology as a complementary tool.

What biotechnology can offer

A wide range of nonconventional methods has been applied to banana ever since the advent of plant biotechnology. Micropropagation of bananas has grown from early experiments (Ma and Shii, 1972) to an industry on its own, which markets approximately 100 million *in vitro* plants. These plants are preferred for the establishment of new plantations or the rejuvenation of existing ones because of their uniformity during the first cycles of production. The occurrence of off-types, that are undesirable for plantations, has also become a frequent means to identify novel useful variants, though without a major breakthrough for the industry so far. *In vitro* culture was further combined with various mutagenesis procedures from the late 1980's (Omar et al., 1989; Novak et al., 1990) in order to increase the range and frequency of variations to be induced. Apart from a few mutants generated (Anonymous, 1990) and the limited distribution of a few of these mutants no significant results have been obtained.

More sophisticated *in vitro* protocols were also developed, which resulted in the establishment of highly regenerable embryogenic cell suspension (ECS) cultures. First,

somatic embryogenesis was achieved from different vegetative tissue explants such as rhizome fragments or leaf bases (Novak et al., 1989; Lee et al., 1997), *in vitro* proliferating meristems (Dhed'a et al., 1991) and male flower bud primordia (Escalant et al., 1994). Then, long-term regenerable ECS cultures were established from proliferating meristems (Dhed'a et al., 1991) as well as from immature male flowers (Cote et al., 1996). Besides direct plant regeneration these ECS provided an excellent source for regenerable protoplasts (Panis et al., 1993; Megia et al., 1993).
The production of regenerable ECS and protoplast cultures made it possible to transfer foreign genes into banana. Successful genetic transformation was first demonstrated in electroporated protoplasts by the transient expression of the *uidA* reporter gene (Sági et al., 1994). Later, the first transgenic banana plants have been produced via microparticle bombardment of ECS cultures with a simple particle inflow gun (Sági et al., 1995) and progress has also been made in *Agrobacterium*-mediated transformation. The compatibility between *Agrobacterium* and various banana tissues was demonstrated during the early phases of the interaction (Pérez Hernández et al., 1999). In addition, several reports indicated that generation of transgenic plants after cocultivation with *A. tumefaciens* of meristematic *in vitro* tissues or ECS cultures (May et al., 1995; Ganapathi et al., 2001; Khanna et al., 2004) has become routine and the method of choice for banana (Pérez Hernández et al., 2006a), though integration of T-DNA may follow unusual and complex patterns (Pérez Hernández et al., 2006b). The high efficiency of the procedure has recently allowed the generation of large transgenic populations tagged with novel promoter and gene trapping constructs (Remy et al., 2005), thus entering the phase of genome-scale applications.

The introduction of large-insert libraries (Vilarinhos et al., 2003; Safar et al., 2004) and high-throughput sequencing techniques for banana research has indicated the arrival of the genomics era in this field. A first insight into the fine structure of the banana genome was gained by nucleotide sequence analysis of random BAC clones (Aert et al., 2004). Moderate or large scale transcriptome analyses have also been performed using EST sequencing (Santos et al., 2005) and profiling by SuperSAGE (Coemans et al., 2005). Microarray experiments are under preparation or underway in several laboratories (unpublished).The current question is how all these technologies, which are by now adapted and available for banana, as well as the knowledge and information gathered can be utilised for meaningful purposes?

Back to the future

One obvious application is transgenic enhancement by the introduction of useful traits into banana. Several candidate genes were tested mainly with the aim of creating resistance to diseases and pests (Chakrabarti et al., 2003; Atkinson et al., 2004; Pei et al., 2005). However, encouraging laboratory results have not been confirmed in successful field trials yet. A major hurdle to progress in transgenic field testing of banana is still the lack of biosafety regulations and/or professional management in many tropical countries.

A further important consideration is precise and regulated control of transgene expression, for which promoters highly active in banana are required. Serious investments in this area resulted in the identification and characterisation of a number of novel promoters, though mainly of viral origin (Schenk et al., 1999, 2001; Yang et al., 2003). These promoters were strong and constitutive in expression pattern and will less likely be accepted in commercial products. More interesting promoters, e.g. fruit- and other tissue-specific or developmentally regulated ones, can be expected from promoter tagging programs (Remy et al., 2005). Further traits with additional benefits for the consumer rather than the producer are under investigation such as transgenic control of fruit ripening and extension of the edible vaccine concept to banana. In both cases, high fruit-specific expression of target genes is a prerequisite because present results indicate low expression rates in banana fruits (Kumar et al., 2005).

One conclusion from past decade's experience in biotechnology of banana and crop plants in general is the notion that the key for genetic enhancement at practical scale is integrated understanding of the target trait(s). For the identification of the right candidate genes as well as the precise regulation of their expression, and for the complex characterisation of plant-pathogen interactions genomics and other high-throughput technologies hold a great potential and will contribute to a next leap into a brighter future of banana.

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Biological and economic impact of the release of an exotic diamondback moth parasitoid *Diadegma semiclausum* (Hym. Ichneumonidae) in Kenya

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Abstract

Pre and post-release studies were conducted in farmer-managed crucifer fields in Taita Hills to assess the biological impact of the introduction of an exotic parasitoid, *Diadegma semiclausum*. Fortnightly, diamondback moth (DBM) populations and damage were assessed in fifteen farmers' fields. Larvae and pupae were collected to assess parasitism and cage exclusion experiments were conducted 7 and 12 months after release to assess parasitoid contribution to mortality.

Before release, population dynamics was bimodal with peaks of 15.8 (Oct.-Nov.) and 7.9 DBM/plant (Jan.-Feb.). Most farmers applied insecticides weekly. In the first year after release, peaks declined to 5.5 and 1.9/plant, respectively. Average annual population before release was 5.8 and the damage score (1-5 scale) was 1.9. Population declined to 3.6 (year 1) and 0.7 (year 2), percentage attached plants were reduced from 72.3 to 30.9% and plants with economic damage from 21.4 to 5.3% (before and year 3 after release, respectively). Parasitoid-attributed mortality of larvae in cage exclusion experiments increased from 18.0% 7 months after release to 65.0% after 12 months. Data from exclusion experiments and field collections indicate displacement of indigenous parasitoids.

The potential economic impact of the introduction of the parasitoid for the Kenyan cabbage industry was analysed starting with crop loss assessment in farmer-managed fields and through farmers' interviews in six districts. Crop losses before release were calculated at 31% (6.8 tons/ha or US$ 452.9/ha) and 36%, respectively, and the total loss for the whole country was US$ 7.9 million per year (at 31%). Control costs, as provided from the interviews, amounted to US$ 118.9/ha. The economic surplus produced by the

release of the parasitoid was estimated at US$ 28.3 million over a period of 25 years. This was based on a net present project value of US$ 1.2 million, an annual cabbage production of 256,524 tons, a cabbage price of US$ 66.3/ton, and as benefits an assumed 30% abatement of yield losses and a 7.9% reduction in cost of production. Consumers were estimated to get 58% of the benefit and producers 42%. The benefit–cost ratio was predicted at 24:1, with an internal rate of return of 86%.

Keywords: Biological control, Diamondback moth, parasitoids, economic impact assessment, Kenya

Introduction

Cabbage, *Brassica oleracea* var. *capitata* L., is one of the most important vegetables grown in Kenya and in East Africa at large. It is eaten raw in salads or cooked, and generates substantial income for the producers and other agents involved in the marketing system. Cabbage is grown in all of Kenya's eight provinces, but mostly at altitudes of 800 - 2000 meters. The major growing provinces are Central and Rift Valley provinces with 40% and 39% of total national production (Macharia et al. 2005). Average annual production from 1999 to 2002 is 256,524 tons, from which a consumption of 25g/person/day can be estimated. In the local farming systems, it is usually part of a diversified cropping pattern, and is mostly grown as a cash crop for the local market.

Major constraints of cabbage production in Kenya, like in other tropical countries, are pests and diseases. In Kenya, insect pests include the diamondback moth (*Plutella xylostella* L.), and three species of aphids (Oduor et al., 1996). Unfortunately no yield loss data are available for any of these pests, however, chemical control for DBM has become difficult and even uneconomical (Kibata, 1996b). The use of synthetic pesticides often leads to serious environmental problems besides affecting the health of users and consumers. They also eliminate the natural enemies of DBM, creating the need for more pesticides, increasing production costs, and lead to the development of insecticide resistance. To overcome resistance, farmers resorted to increasing frequency and doses of pesticide applications and to insecticide cocktails. As a result, the costs of DBM control escalated to US$ 1 billion world wide for insecticides alone (Talekar and Shelton, 1993).

An important alternative to the calendar-based application of synthetic pesticides is integrated pest management (IPM), which can greatly reduce the environmental and human health costs. One of the major tools in IPM is biological control. Natural biological control occurs in almost every production system and these natural control agents can be encouraged in many ways to improve their pest control capabilities and thus delay or even replace the use of synthetic pesticides. Where existing natural control agents cannot cope with the pests and especially where pests have been introduced to areas where they were not present before, classical biological control, the deliberate introduction of known control agents from the area of origin of the pest, is often used to achieve permanent control of the introduced pest. To develop and promote effective, economical and environmentally acceptable DBM control, the International Centre of Insect Physiology and Ecology (ICIPE) initiated a biological control programme for Eastern and Southern Africa. After an evaluation of the indigenous natural enemies failed to identify a specific and effective diamondback moth parasitoid (Löhr and Kfir, 2003), a decision was made to introduce *Diadegma semiclausum* (Hellén) (Hym.: Ichneumonidae) (Talekar, 1992; Poelking, 1992)*Diadegma semiclausum* is arguably the most successful parasitoid of the diamondback moth (DBM), *Plutella xylostella* (L.) (Lep.: Plutellidae). It has been widely and successfully used over large areas of southeast and south Asia when pesticide resistance of DBM had lead to the failure of crop protection programmes in crucifer production (Lim *et* al, 1996; Shelton *et al*, 1996; Uk and Harris 1996). First efforts at classical biological control of DBM took place in New Zealand where the species was introduced from England (Hardy, 1938). It was also introduced to Indonesia in the 1950s but its full potential to control of DBM was only realized after 1989 with the introduction of biopesticides (Sastrosiswojo and Sastrodihardjo, 1996). In Taiwan, the parasitoid was imported from Indonesia and resulted in more than 70% parasitisitism in highland areas (Talekar, 1992). Unfortunately, no rigorous economic impact assessment was conducted for any of these introductions (Waibel and Pemsl, 2000).

Impact assessment of biological control in Africa started with the biological control of the cassava mealy bug. It was first assessed using secondary data and by extrapolation of major assumptions of increased yield (Norgaard, 1988). Its positive results were confirmed by Zeddies et al. (2001) with a detailed modeling for 27 countries and an extrapolation over a 40-year period. Other economic impact studies were conducted for the biological control of the mango mealybug (Vogele et al., 1991; Bokonon-Ganta et al., 2002) and water hyacynth (De Groote et al., 2003).

The present study is the first attempt to combine biological and economic impact assessment and thus quantify the full benefits of diamondback moth biological control after more than 20 years of intensive research and extension efforts on the topic. It is also the first *ex-ante* economic impact study of biological control, including both determination of crop losses and impact assessment at the level of beneficiaries.

Methodology

Biological impact assessment

In order to assess the biological impact of the release of *D. semiclausum,* long-term observations of DBM populations and parasitism were initiated at Werugha location, Wundanyi Division in Taita Taveta District, Coast Region of Kenya. Studies were conducted in farmers' fields from April 2001 and carried through for one year before and three years after release. Fifteen farmer-managed farms were sampled fortnightly for one year before and after the release of the exotic parasitoid, then monthly for another two years. Ten plants were selected at random in each field and thoroughly checked. The DBM numbers were recorded and a sample of DBM larvae or pupae were collected from each plant for the assessment of parasitism. On July 26th, 2002, 25 pairs of *D. semiclausum* were released in five fields.

The impact of the release on DBM mortality and indigenous parasitoids was also studied in cage exclusion experiments 7 and 12 months after release. Lab-infested plants (60 neonate larvae each) were exposed to parasitoids in the field in cages. Half of the cages were open to allow for parasitoid access, half were closed. An additional treatment was the application of insect glue at the plant base against crawling predators. Infested leaves were harvested every other day and the contribution of indigenous and introduced parasitoids to larval mortality was assessed. In addition, larvae were collected in the field to compare mortality factors in a more natural situation.

Economic impact assessment

The linear economic surplus model (Alston et al., 1995) was used for economic impact assessment. The framework requires production, economic, and crop loss data. The economic and production data were found through farmers' interviews and secondary data, crop loss data were obtained through direct measurements from farmer managed fields and yield loss estimates from farmer interviews.

Production, economic, and crop loss data were combined into the economic surplus model. Assumptions of the model include: linear supply and demand functions, and a vertical shift of the supply function. Estimates of supply and demand elasticity could not be found in the literature. For the semi-subsistence farming system and in the absence of better information, supply response parameters for agricultural crops in developing countries like Kenya are often approximated with a value close to one (Alston et al., 1995). We assumed a supply elasticity of 0.9. Given that the price responsiveness of demand is usually higher in the developing countries, a demand elasticity coefficient of -1.4 was assumed (Qaim, 1999). Because of high population growth in Kenya and expectation of higher demand in future an annual growth rate of 2.6% on average (World Bank, 2000) was used to refine the demand situation expected. With these parameters built in a closed economy because very little of cabbage is exported; economic surplus was calculated using Dynamic Research Analysis for Management (DREAM) software.

Results

Cabbage production systems

The survey of 68 cabbage producers in six districts revealed that most cabbage producers operate mixed production systems with an average of 2.06 ha of farmland. Cabbage covered 14% of the total area, or 0.29 ha (Table 1). Average yield was 19.47 tons/ha or 5 tons/farm but varied widely between the districts: from 11.2 tons/ha in Kisii North to 41.6 tons/ha in Meru. The average price was US$ 58/ton, the revenue US$ 1245.1/ha. Total production cost amounted to US$ 625.42/ha, with 16% going to pesticides. The average gross margin was US$ 619.63/ha per season (Table 2). Assuming the benefits are constant over the year and the farmer can have two production periods per year, benefits of US$ 1239.26/ha or US$ 359.38/farm can be expected. Per unit cost was much higher for Nyeri, (US$ 62/ton) and lower for Meru (US$ 13.6/ton) with an average of US$ 57.35/ton (Table 2).

DBM population and damage before and after release

Diamondback moth dynamics was bimodal (Figure 1) with peaks during the dry seasons. Higher counts were recorded during the months of September – November and again January – March, reflecting the rainfall pattern. The highest mean number of DBM/plant in any of the collections was reached during the pre-release year on October 16, 2001 (16.8/plant, not shown), in spite of the bi-weekly insecticide applications of most farmers. The after release population curve indicates a considerable reduction in DBM numbers starting already from three months after release. The population curve showed a steadily declining trend for the three after-release years with the bimodal population dynamics still clearly visible but greatly decreased amplitude (Figure 1).

Average population density during the 12 months pre-release study was 5.4 DBM/plant (Table 3). This value declined significantly in the first year after release and even more sharply in the second year to 0.7 DBM/plant and then remained stable. Similarly, the percentage of attacked plants declined in the first and second year after release and then remained stable at around 30%. The damage score increased from the year before release (1.9) to the first year after but then declined and attained a significantly lower value (1.5) in year three after release (Table 3). The changes in the proportion of plants in damage score >2 also increased in the first year after release but declined by a factor of four to 5.3% at the end of the observations.

Development of parasitism

Pre-release parasitism was low from April 2001 until February 2002 when the total parasitism surpassed 20% for the first time (Figure 2). The highest level reached was 38.3% at the beginning of April (not shown) and from the end of May, the rate dropped sharply again. *Oomyzus sokolowskii* (Hym.: Eulophidae) was the parasitoid responsible for this rise and was the only parasitoid with strongly expressed seasonality (Figure 2). *Diadegma mollipla* was present in most collections, even though at a very low level. Already the first collection after release (August 2002) yielded *D. semiclausum* and even though initial numbers remained low until mid February 2003, the species was present in all collections. From the end of February, *D. semiclausum* parasitism surged and peaks of 80% parasitism were reached in March 2004 and again in June 2005. From June 2003 onwards, the indigenous parasitoids disappeared almost completely and only *Diadegma mollipla* parasitism recovered slightly starting from June 2004 (Figure 2).

Even though the number of specimens collected for laboratory rearing to establish levels of parasitism cannot be considered strictly a parameter (and was thus not subjected to statistical analysis), the decline of 50% in the first year and of 89.8 and 88.6% (year 2 and 3, respectively) indicates the huge reduction in the field population of the pest (Table 4). The major parasitoid species recorded before release of the exotic species were *O. sokolowskii* and *D. mollipla*. The former declined almost to extinction after the release (Table 4) while the latter recovered after a sharp decline in years 1 and 2. Minor parasitoid species collected were *Itoplectis* sp. (Hym.: Ichneumonidae) (74 specimen before, 50 after release) and *Apanteles* sp. (Hym.: Braconidae) (2 before, 3 after release). The introduced parasitoid surpassed the overall parasitism rate of all indigenous species combined already in the first year after its release and the final rate of parasitism was around 50% (Table 4).

Larval and pupal mortality factors

Recovery of exposed larvae was generally low at both sites and in all treatments. Seven months after release, there were no differences in the recovery of larvae between open and closed cages (49,0 and 44.6%). However, while larval recovery remained in a similar range in the closed cages after twelve months (52.1%), recovery of exposed larvae in the open cages had significantly declined to 28.6% (pooled data of open and closed cages).

Parasitism contributed slightly above 20% to the mortality of recovered larvae in open cages seven moths after release, and this value was significantly higher than in the caged treatments (Table 5). *Diadegma semiclausum* contributed considerably more to this mortality than *Oomyzus sokolowskii* in the first experiment and one year after release, the former was the only parasitoid recorded.

Loss abatement

The relationship between yield and damage score was assessed using the data from on farm measurements. A linear regression model was used to estimate this relationship. The results indicate a yield of 25.5 tons/ha for the undamaged crop ($y = 25.5x - 5.68$, $R^2 = 0.55$, $p < 0.001$), and a reduction of 5.7 tons/ha for each increase in damage score by one. The average yield was 17.7 tons/ha with a mean damage score of 1.39, the average yield loss under current condition was 31%. Measurements in farmers' fields and the interviews produced comparable crop loss estimates (38.8 and 36.0%, respectively) and the lowest estimate (31%) was used for all calculations. Yield loss was calculated at 6.8 tons/ha or US$ 452.9/ha. If extrapolated for the country in a completely elastic demand situation, the losses amount to US$ 7.9 million per year.

Two main effects are expected after successful establishment of the parasitoid: an abatement of crop losses and a reduction in pesticide expenditure. With full abatement considering the yields reported from the Ministry of Agriculture, yields of 6.8 tons/ha could be recovered, increasing the yield to 22.0 tons/ha. For our calculation, we assumed a crop loss abatement of 30% of the loss experienced at present.

Economic analysis

An average yield of 15.2 ton/ha, total production of 256,524 tons (average, MoARD, 1999–2002), an average farm gate price of US$ 66.3/ton, 30% abatement of the crop loss, 50% reduction on use of pesticides, a supply and a demand elasticity of 0.9 and -1.4, respectively, and an annual increase in consumption of 2.6% were used for the economic analysis. With these parameters, the economic surplus (present value of the benefits to producers and consumers) is calculated at US$ 28.3 million over 25 years with a 5-year lag. Of the economic surplus, producers will get 42% while consumer will benefit with 58% (Table 6). Details on expenses for the biological control project were obtained from the ICIPE finance office. The costs from 2000 to 2003 were estimated at US$ 647,000 or 49% of the total budget allocated for the whole project covering East Africa. Additional costs of the second phase of the project for the nation-wide releases and monitoring in Kenya were estimated at US$ 873,600.

The total cost discounted at a rate of 10% relative to the base year of 2000, accounts for US$ 1.2 million. The total cost divided by area in cabbage (17,524 ha) result in a cost of US$ 61.8 per ha or US$ 2.5 per ha per year, considering the 25-year period. This cost of development and implementation, assuming other factors remain constant, would be recovered within one year, if only 18% of the yield loss was prevented. Comparing the present value of the expected benefit to the cost, the benefit–cost ratio was estimated at 24:1, with an internal rate of return of 85% (Table 6). As the benefits are likely to increase (by spill-over into other crucifers such as kale, and into neighbouring countries), this figure should be treated as a conservative estimate, to be updated when more evidence become available.

Sensitivity analysis

A sensitivity analysis was conducted to test the robustness of the results by changing several parameters. With the conservative assumption that pest control costs will not decrease, benefits would decrease (from US$ 28.3 million) to US$ 17.5 million, and the benefit/cost ratio would drop from 24:1 to 15:1. When the crop loss abatement was assumed to be 15% (instead of 30%), benefits amounted to US$ 19.2 million, with a benefit/cost ratio of 16:1 (Table 7). With a more optimistic scenario of 75% abatement of yield loss, which can be achieved through widespread establishment of the parasitoid, the benefit–cost ratio became 48:1.

The sensitivity of the result with respect to price was also tested. Using the wholesale price (US$ 103) resulted into an economic surplus of US$ 40.4 million and a benefit–cost ratio of 34:1, while retail price resulted in a benefit–cost ratio of 58:1. Assuming supply elasticity being reduced by half, the benefit–cost ratio was reduced to 23:1. Doubling the discount rate (to 20%) brought the economic surplus down to US$ 9.9 million and the benefit–cost ratio to 10:1. Even in a worst-case scenario with the lowest yield abatement (15%), highest discount rate (20%), low elasticities and low price (US$ 66/ton), the benefit–cost ratio (7:1) still justified the investment in the project (Table 7). These results indicate that even with pessimistic assumptions this biological control will still be profitable.

Discussions and Conclusion

In spite of the multitude of introductions of *D. semiclausum* against DBM in Southeast Asia, long-term studies of parasitoid impact on DBM populations are scarce. Poelking (1992) gave a detailed account of the early impact of *D. semiclausum* releases in the Philippines with >95% parasitism towards the end of the first after-release cabbage season. Ooi (1992) reported from Malaysia that the effect of the introduction of *D. semiclausum* was only felt ten years after release when the farmers were forced to reduce pesticide use due to residue problems. The impact of the introduction on DBM populations at Werugha was similarly fast as reported in the Philippines and was documented Momanyi *et al.* (2006) in field mortality studies of larvae and pupae.

All three experiments document clearly the establishment of *D. semiclausum* and its contribution to larval/pupal mortality of the diamondback moth. At Werugha, the establishment was exceptionally fast and contribution to mortality in the exclusion experiment reached 17 % only six months after release and >50% after one year, in spite of the low number (100 females) of parasitoids released in the whole area. The parasitism data of field-collected larvae largely confirm this fast establishment. Similar observations were reported by Poelking (1992) from the Philippines. However, while we did not find any information from elsewhere about effect of releases of *D. semiclausum* on indigenous parasitoids, we could show that it is a strong competitor and almost completely displaced all indigenous parasitoids, even at rates of parasitism as low as 23.1%.

Studies of the competitive displacement of indigenous parasitoids of *P. xylostella* after the introduction of exotic species are not available in spite of the introductions made in many parts of the world. In our case, the displacement of the in indigenous species by *D. semiclausum* appears to have been caused by the superior host searching capability and better association with cruciferous host plants, at least as far as its congeneric indigenous species is concerned (Rossbach et al. 2005). Unfortunately, similar studies with the other indigenous parasitoids are not available. We assume that all local species must have alternative hosts in addition to DBM and have just made use of a largely unexploited resource, DBM larvae, in the absence of other more specialised parasitoids.

Competitive displacement has been reported across a broad range of taxa and environments (Stuart and John, 2002) with several reasons being given to explain why some parasitoids outcompete others. Factors adduced to influence the outcome of displacement are climate, differences in host searching ability, and better capacity to outwit host or other rival parasitoid's immune response (Stuart and John, 2002). Displacement of indigenous parasitoids by the introduced *D. semiclausum* was documented at the pilot site and from the exclusion experiments. *Diadegma semiclausum* displaced the local natural enemies at relatively low parasitism levels (23% parasitism) at Tharuni. Among the indigenous parasitoids only *O. sokolowskii* is considered a specific diamondback parasitoid (Fitton and Walker, 1992; Shu *et al.,* 2000).

The next most important local species, *D. mollipla,* was shown to have no preference for cabbage plants, no matter whether infested with the host or not (Rossbach *et al*., 2005). It is therefore assumed that this species as well as the even less frequent parasitoids: *Itoplectis* sp. (Hymenoptera: Ichneumonidae) and *Apanteles* sp. (Hymenoptera: Braconidae) may disappear completely from the highland cabbage-growing environment in the near future.

In the present analysis, the Diamondback moth biological control programme was found to be beneficial for Kenya and for the funding agency, with a benefit cost ratio of 41:1. This ratio is somewhat lower than that of other biocontrol projects such as the cassava mealybug over most of tropical Africa (benefit cost ratio of 149:1; Norgaard, 1988), the water hyacinth in Southern Benin (benefit cost ratio of 124:1; De Groote et al., 2002), and the mango mealybug in Benin (benefit cost ratio of 145:1; Bokonon-Ganta et al., 2002). However, the benefit value calculated can be considered as a lower boundary, since the calculation used the least favorable case of yield loss abatement, and did not include other benefits like loss abatement in other crucifers crop e.g. kales, cauliflower and broccoli. It has also to be taken into consideration that most of the project costs were allocated to operations in Kenya while beneficial effects will also accrue in neighbouring project countries, and could be easily extended at minimum cost to non-project countries. Additional benefits like the possibility of increase in market value for pesticide free cabbage, reduced health hazard of farmers and consumers, and others related to the reduction of externalities related to pesticide use are more difficult to quantify and will be the subject of follow-up studies at a later stage. Efforts at quantifying benefits to the environment in monetary terms have generally been confronted with difficulties and the

need for a more strategic approach to ecological impact assessment has been identified (Treweek, 1996). Methodology for this has already been developed (Waibel and Fleischer, 1998) and activities will be started soon.
This study concentrated on cabbage grown in the highlands. In Kenya, cabbage occupies slightly less land than the area covered by kale, a leafy cabbage consumed every day by most Kenyans of the lower income bracket. Kale extends beyond the highland growing conditions of cabbage into the semi-arid lowlands of Kenya. While cabbage is grown for the market, kale is most important as a subsistence crop with excess production marketed. This requires a different approach for impact assessment.

The study also confirms once more the huge potential of carefully planned and implemented biological control projects. Such projects can bring huge benefits, especially for cash-strapped smallholder producers as they have no follow-up costs after introduction and a potential ever-lasting benefit.

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Table 1 Regional aspects of cabbage production in selected districts of Kenya. (Macharia et al. 2005).

Table 2 Average production cost and income figures for cabbage farmers in Kenya. (Macharia et al. 2005).

Table 3 Diamondback moth population and damage before and after introduction of the exotic parasitoid, *Diadegma semiclausum*. Werugha, Coast Province of Kenya.

Means with different superscript letters within a column are significantly different ($P<0.05$), Tukey's Honest Significant Difference Test

Table 4 Field parasitism of Diamondback moth before and after introduction of the exotic parasitoid, *Diadegma semiclausum*. Werugha, Coast Province of Kenya.

Means with different superscript letters within a column are significantly different ($P<0.05$), Tukey's Honest Significant Difference Test.

Table 5 Mortality factors of Diamondback moth (*Plutella xylostella*) *larvae* and pupae in cage exclusion experiments at Werugha, Wundanyi Division, Coast Province of Kenya.

Means within the same column followed by the same letter are not significantly different at $P<0.05$, Student-Newman-Keuls test for comparison of means. (Momanyi et al. 2006).

Table 6 Economic surplus expected from the introduction of an exotic parasitoid species for biological control of the Diamondback moth in cabbage and its distribution between producers and consumers. (Macharia et al. 2005).

Table 7 Sensitivity analysis for parameters used in the economic impact assessment of the introduction of an exotic parasitoid species for biological control of the Diamondback moth in cabbage. (Macharia et al. 2005).

Figure 1 Dynamics and composition of a diamondback moth population before and after release of an exotic parasitoid. Werugha, Taita Hills, Coast Province of Kenya. Data were collected from 10 plants in each of 15 farmer-managed fields. Up to three sampling dates within one month (April 2001-July 2003) were pooled.

Figure 2 Variation in field parasitism and parasitoid guild composition of diamondback moth before and after release of an exotic parasitoid. Werugha, Taita Hills, Coast Province of Kenya. Data were collected from 10 plants in each of 15 farmer-managed fields. Up to three sampling dates within one month (April 2001-July 2003) were pooled.

Compatibility of insect-resistant transgenic plants with biological control

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Insect resistant transgenic crops that express *cry* genes derived from the soil bacterium *Bacillus thuringiensis* (*Bt*) are grown on a steadily increasing area worldwide since their first introduction in 1996, reaching a total of 26.3 million ha in 2005 (James, 2005). *Bt* (Cry) toxins are known to have a very specific mode of action and they have a long history of safe use in the form of microbial *Bt* products (Glare & O'Callaghan, 2000). The majority of *Bt* maize plants that are commercialized express either a Lepidoptera-specific Cry1 toxin that targets stem borers (mainly *Ostrinia nubilalis*) or a Coleoptera-specific Cry3 toxin for the control of corn rootworms (*Diabrotica* spp.). *Bt* cotton plants that are available express Lepidopteran-specific toxins targeting the budworm-bollworm complex (*Heliothis virescens*, *Helicoverpa* spp., *Pectinophora gossypiella*). Besides single gene cotton plants (expressing *cry1Ac*), plants that express two genes (*cry1Ac* and *cry2Aa*) have recently been released to provide a much more efficient and reliable control of the pest complex (AGBIOS database, http://www.agbios.com). Acceptance of *Bt* crops by farmers has been exceptional. In 2005, China grew *Bt* cotton on a total of 3.3 million ha (65% of the total cotton area) and in India, officially released *Bt* cotton varieties were grown on 1.3 million ha (James, 2005). It is estimated that in 2005 approximately 6.4 and 1 million small scale farmers planted *Bt* cotton in China and India, respectively (James, 2005). Other countries in which *Bt* cotton is registered for commercial use include Argentina, Australia, Columbia, Mexico, South Africa and the USA (James, 2005). A number of other insecticidal proteins including protease inhibitors, α-amylase inhibitors, biotin binding proteins or lectins have also been introduced in crop plants for pest control. However, none of these plants has been commercialized yet and they are generally less specific in their mode of action when compared to *Bt* Cry proteins with higher intrinsic risks for non-target organisms (O'Callaghan *et al.*, 2005).

While in some areas of the world, especially in Europe, the debate is focusing on the potential environmental risks that could be a consequence of the large scale deployment of *Bt*-transgenic crops, other countries are investing time and efforts to evaluate how these crops can be implemented in integrated pest management (IPM) programs for sustainable pest control. It is generally accepted that *Bt* crops should not be viewed as silver bullets to solve all insect pest problems but should be regarded as another tool to manage certain pest populations in an economically viable and environmentally safe manner. One factor of particular interest in this respect is the impact of *Bt*-transgenic crops on non-target organisms that provide important ecological and economic services within the agricultural system. This includes pollinators, decomposers and biological control agents such as parasitoids and predators that are of importance for natural pest regulation. Therefore the potential risk that *Bt*-transgenic plants pose for non-target arthropods needs to be assessed prior to commercialization (Dutton *et al.* 2003; Conner *et al.*, 2003). Since their introduction ten years ago, a number of peer-reviewed studies have addressed the effects of *Bt* crops on arthropod biological control agents under confined conditions (laboratory, glasshouse) and in the field (O'Callaghan *et al.*, 2005; Romeis *et al.*, 2006).

The impact of *Bt* plants on predators and parasitoids has been assessed both in tri-trophic (plant–herbivore–natural enemy) and bi-trophic (plant–natural enemy) systems. The studies available to date provide no evidence that the Cry toxins expressed caused direct toxic effects on the natural enemies (Romeis *et al*., 2006). This was expected based on the known specific mode of action of the toxins deployed. However, adverse effects on some predators and all parasitoids tested were observed when *Bt* susceptible herbivores were used as prey or hosts. Since the herbivores were sublethally damaged by the ingested *Bt* toxin they appeared to be of lower nutritional quality for the natural enemy, causing so-called prey-quality mediated effects. Especially parasitoids are known to have very tight relationships with their hosts and are thus very sensitive to changes in host quality. By far the best studied natural enemy is the green lacewing, *Crysoperla carnea*. Larvae of this predator were found to be not sensitive to lepidopteran active Cry1 toxins when directly fed in artificial diet studies (Romeis *et al*., 2004; Rodrigo-Simón *et al*., 2006). Similarly, larvae where not affected when fed spider mites that had been reared on Cry1Ab expressing *Bt* maize (Dutton *et al*., 2002) even so the mites were found to contain large amounts of active *Bt* toxin (Obrist *et al*., 2006). In contrast, negative effects were reported when the predator larvae were fed lepidopteran larvae reared on *Bt* maize (Dutton *et al*., 2002). However, from the direct toxicity studies noted above, it can be concluded that these effects were a consequence of sublethally intoxicated lepidopteran prey, apparently being of lower nutritional quality (prey-quality mediated effects). Since lepidopteran larvae are not regarded to be an important food for this predator in the field, the risk that *Bt* maize poses to this predator species can be regarded as negligible (Dutton *et al*., 2003). These findings have now been confirmed by a number of field studies (e.g. Candolfi *et al*., 2004; de la Poza *et al*., 2005; Pilcher *et al*., 2005). The *C. carnea* example shows that well-designed laboratory studies can, with a high degree of certainty, exclude negative effects in the field.

Experimental field studies have only revealed minor, transient or inconsistent effects of *Bt* crops on natural enemies when compared to a non-*Bt* control (Romeis *et al*., 2006). Exceptions were observed with specialist parasitoids and predators which were virtually absent in *Bt* fields due to the lack of target pests as hosts or prey (Riddick *et al*., 1998; Pilcher *et al*., 2005). Also consistent reductions in the abundance of some generalist predators have been reported in *Bt* cotton (Naranjo, 2005a; Whitehouse *et al*., 2005) and *Bt* maize (Daly & Buntin, 2005). Again, these effects have been associated with the reduced availability of prey insects that are the targets of the *Bt* technology. Furthermore this reduction does not appear to be of ecological significance. A six-year field study in *Bt* cotton on the abundance of 22 arthropod natural enemy taxa indicated that an average decrease of about 20% in some predatory species did not appear to reduce the biological control function of the natural enemy community (Naranjo 2005a,b). Negative effects on natural enemies that depend on the target pests are a common consequence of every pest control method including insecticides, biological control, and conventional host-plant resistance and are generally not considered as a risk (Romeis *et al*., 2006). Since the sensitive (target) herbivores will largely be controlled by the *Bt* crop in the field, the use of those organisms for non-target risk assessment studies in the laboratory is therefore more than questionable.

Since one aim of *Bt* crops is to replace or reduce applications of chemical insecticides, the most common conventional mode of pest control, a comparison between these two technologies needs to be done in those cases (Dale *et al*., 2002; Conner *et al*., 2003). Field experiments that included broad spectrum insecticides, such as pyrethroids and organophosphates, have consistently resulted in reduced abundances of natural enemies. Side effects of more selective insecticides such as indoxacarb (oxadiazine) or spinosad (macrolide) largely depended on the spray frequency whereas systemic insecticides (such as imidacloprid, a neonicotinoid) were found to have no or little effect on natural enemies (Romeis *et al*., 2006). In general all these studies indicate clearly that non-target effects of *Bt* crops are substantially lower than that of most insecticides currently used. Two recent large scale studies conducted in commercially managed *Bt* and non-*Bt* cotton fields in the USA have revealed substantially higher natural enemy communities in *Bt* cotton where insecticide applications were significantly reduced (Head *et al*., 2005; Torres & Ruberson, 2005). In cotton fields, broad-spectrum insecticides are generally applied for the control of lepidopteran pests, i.e. the bollworm-budworm complex. In Asian countries such as India or China, cotton crops may be sprayed more than 10 times in a year in an attempt to control severe lepidopteran pest outbreaks (Wu & Guo, 2005). Around the globe, deployment of *Bt* cotton has resulted in a 60-80% decrease in the use of foliar insecticides in this crop (Fitt *et al*., 2004). This reduction not only has consequences for the natural enemy communities but also clear health benefits for farm workers (Hossain *et al*., 2004) as well as economic benefits (Qaim & Zilberman, 2003). The recently introduced double gene cotton has been found to lead to even greater reductions in insecticide use. Similarly to cotton, *Bt* sweet-corn has been found to be a suitable alternative for control of lepidopteran pests and can lead to large reductions in insecticide use (Musser & Shelton, 2003). In other crops such as maize, the introduction of the *Bt* gene to control *Ostrinia nubilalis* has not lead to substantial insecticide decreases due to the fact that this pest is generally not controlled by foliar insecticides so many growers simply did not treat and were resigned to the losses (Phipps & Park, 2002).

Due to their specific mode of action and the fact that they largely replace broad spectrum insecticides, the sustained value of *Bt* crops in IPM systems requires focus on the management of secondary pests, which are under control of the insecticides in the conventional crop. Enhanced levels of beneficial species in the *Bt* fields help to partially suppress secondary pests as has been reported for aphids (Reed *et al*., 2001; Wu & Guo, 2003). In contrast, plant feeding bugs (Miridae and Pentatomidae) have regionally developed pest status in *Bt* cotton since they had earlier been under control by broad spectrum insecticides applied against lepidopteran pests (Green *et al*., 2001; Wu *et al*., 2002).

The amount of data that is available to date provides evidence that the *Bt* crops grown today are more specific and have fewer side effects on parasitoids and predators than most insecticides currently used. In crops where the deployment of *Bt*-transgenic varieties leads to a substantial reduction in insecticide use (i.e. cotton and sweet-corn) they can form an important component of an IPM system with an active biological control function. Thus *Bt*-transgenic crops should be regarded as a biocontrol friendly technology that can help promote the conservation of biological control agents for key pests in cropping systems that are currently dominated by insecticide use.

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ProVitaMinRice : Preventing multiple micronutrient deficiencies using biofortification

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Micronutrient deficiencies create a vicious circle of malnutrition, poverty and economic dependency that we must strive to break. The *Golden Rice* Project offers a sustainable solution to a problem that affects the health of millions of people all over the world. While the approach involves high tech, the user gets simply a nutrient-dense crop, requiring no additional knowledge for its handling.

One of eight UN Millenium Development Goals is to reduce child mortality by two-thirds by the year 2015. More than 10 million children die every year unnecessarily, 90 percent of the casualties are concentrated in only 42 countries (Black et al. 2003). According to the World Health Organization (WHO), clinical to severe sub-clinical vitamin A deficiency (VAD) affects most developing countries. Simple measures, like breastfeeding, vitamin A and zinc supplementation could reduce the death toll by 25 percent. The combination of individual measures is capable of producing an effect that is greater than their sum (Jones et al. 2003).

In rice-based societies, daily food intake may comprise over 80 percent rice, as is the case in rural Bangladesh. Other components are vegetables (ca. 12 percent) and very little fish and other animal sources. In such countries, rice is also the main source of lipids and protein, even though milled rice contains only about 0.4 and 7 percent of these nutrients, respectively. This leads to a situation of well-fed people in terms of calories but malnourished in respect of a number of other essential nutrients.

Milled rice is poor in essential micronutrients. The problem with brown (unprocessed) rice—which contains some important micronutrients—is that it may not be stored for too long, because lipids contained in the outer layers undergo oxidation, rendering the grains rancid and unpleasant to the taste.

There is a clear association between VAD and a higher mortality rate among young children (Sommer and West Jr. 1996). The severity of VAD correlates with ocular signs, mainly xerophthalmia and its associated symptomatology, i.e. night blindness and corneal degeneration.

About half of the children that become blind as a consequence of VAD die from various diseases, like measles or malaria, within a year of becoming blind.

Various intervention strategies have achieved notable results in a number of countries, yet even in the best cases approximately 30 percent of the population remains VA deficient. In average 55 percent of the children are covered by these interventions, but in countries like Peru, 90 percent of the children remain uncovered.

Typical interventions are education, industrial fortification, and supplementation. Industrial fortification, e.g. distribution of iodine-enriched salt or vitamin A-enriched margarine, is a common conduit to administer essential nutrients to an affluent population. Supplementation consists of providing children with one or two megadoses of vitamin A per year, usually as capsules. Serum retinol (vit A) levels drop significantly between interventions.

These interventions, currently being carried out by a numbers of national and international organizations, are limited by the logistic requirements of distribution networks—tens of thousands of helpers must be periodically mobilised—and the need for centralised processing. They are also affected by geographical limitations, making them only partially applicable. Even though the cost of the capsules and other supplements is very low, the cost of the campaigns, even for a small country the size of Nepal or Ghana, is in the range of US$ 2 million per year (MOST 2004). Furthermore, these campaigns do not reach children older than five nor pregnant or lactating women. These limitations make supplementation unsustainable in the long term.

Industrial fortification—which requires centralised processing—is hard to achieve in poor agricultural societies, where the produce of the land is consumed by the farmer and his family or traded locally. This sector of society is often served using the supplementation approach, i.e. by administration of capsules and the like. These programmes are usually linked to vaccination campaigns and other health-related services. Sadly, such campaigns usually do not attract mothers with children to the attention centres more than once a year. Urban areas are more accessible to supplementation programmes, but even though the share of urban population is constantly increasing all over the world, most countries with severe VAD are rural societies. Every affected country requires individually tailored programmes and relies mostly on foreign help and government goodwill. This explains why, according to UNICEF, in 1999 only 43 countries, out of 100 countries in need of supplementation, received 70 percent coverage of one yearly megadose to children under five years of age.

Biofortification represents a viable alternative for micronutrient delivery. This approach consists of plants producing or accumulating the desired nutrients in the edible parts. Traditionally, this is achieved by breeding (e.g. orange-fleshed sweetpotato), unless the desired trait is not available in existing, sexually compatible germplasm (as in rice). Biofortification offers a sustainable solution with the potential to complement current interventions and fill in existing coverage gaps left by supplementation programmes. The advantages of biofortification are evident: the generation of a plant variety is a one-off investment. In the case of genetic engineering, the research phase can involve a high initial investment, justifiable by the expected socioeconomic impact. But once a trait has been engineered into a variety it can be easily transferred to any locally adapted variety by traditional breeding.

In poor, rice-based societies 3.8 million children die every year, that is 10,440 actual children deaths per day (Jones et al. 2003). People in such countries are the target population for programmes involving biofortified rice. Thanks to the Green Revolution of the 1960s, cereal production has been able to keep pace with population growth in developing countries, while other important crops, like pulses and vegetables, have lagged behind. Furthermore, the Green Revolution has brought prices for cereal crops down in the last 30 years, while prices for other food sources have increased. Biofortified cereals are thus again ideally suited for the task.

In the case of rice, biofortification is limited by the fact that there is no germplasm available among cultivated or wild relatives containing any provitamin A. A 1992 initiative by the Rockefeller Foundation led Prof Ingo Potrykus (ETH Zurich) and Prof Peter Beyer (University of Freiburg) to embark on the engineering of the provitamin A biosynthetic pathway in rice grains (Ye et al. 2000). At the end of an intensive basic research phase, a relatively simple genetic intervention provided a solution to a seemingly intractable problem. The result is now widely known as *Golden Rice* (GR). The only difference between GR and traditional rice is the carotenoid content and the pleasant golden colour of the grains.

All green plants synthesize carotenoids in leaves and very often in flowers. We obtain many of our dietary carotenoids from yellow fruits. In the rice grain, only two steps of a complex pathway leading to the production of carotenoids are interrupted. In GR the gap has been rebuilt by a genetic intervention involving the introduction of two genes, one of bacterial and another of plant origin. The bacterial gene from *Erwinia uredovora* is a carotene desaturase (CRT I), which catalyses the conversion of phytoene to lycopene. The gene of plant origin, originally from daffodil but isolated from maize in the newest constructs, is a phytoene synthase (PSY), which catalyses the conversion of geranygeranyl bisphosphate to phytoene (Paine et al. 2005; Schaub et al. 2005). These two steps at the entry point of carotenoid biosynthesis completely restore the pathway in the rice endosperm, leading to the preferential accumulation of beta-carotene (provitamin A).

It took five years from the breakthrough achievement of the first GR version to the first field trial! Contrary to what many external observers believed, putting the technology access agreements in place was the least of the problems. In exchange for rights to their invention, Beyer and Potrykus obtained access to a technology package owned by various companies, for humanitarian purposes. Smallholders in developing countries will have free access to GR technology with no strings attached, except for a yearly income cap of US$10,000, which is above the income level of smallholders in the target countries. So, why the delay? The major hurdle to progress of the GR Project remains regulatory in nature.

But the developers of GR have not rested on their laurels. Against the odds of destructive criticism by opponents of gene technology, GR has been further developed to accumulate enough beta-carotene to cover the recommended daily intake (RDI) in rice-based societies. The GR technology has been improved steadily, pushing the production and accumulation levels of beta-carotene higher and higher. To a great extent, progress has been possible thanks to the continuing support from Syngenta. The company has provided access to needed technologies and has also actively participated in producing *regulatory clean* lines and developed improved versions of GR (Paine et al. 2005). By exchanging the original daffodil PSY gene for a maize homolog, researcher at Syngenta were able to overcome the rate-limiting step of the reaction and thus obtain carotenoid levels 23x higher (and more) than in the first GR obtained in 1999. Lines with beta-carotene values between the first GR version and the new one had already been obtained by using endosperm-specific promoters and by selecting the best transformed lines. Remarkably, the overproduced carotenoids consist of more than 80 percent beta-carotene (provitamin A).

An international network, consisting of national agricultural research institutions, has been set up in target countries to guarantee outreach of the GR Project to the malnourished poor in those countries. Every institution in this so-called *Golden Rice* Network is involved in breeding of locally adapted GR varieties and making sure that planting material reaches the farmers. This is achieved by introgression of the beta-carotene production trait from a regulatory clean variety into local varieties, a process that may take around two years to complete.

The first GR field trial took place in the USA, because it was the only country that had in place pragmatic, science-based biosafety regulations. Permits for trials in India and the Philippines were not signed off in time for the rice-growing season. Various versions of GR are now finally growing in greenhouses in the Philippines, India, and Vietnam. The first field trials in Asia will take place later this year. In the meantime, two trials have already taken place in the US, whereby no agronomic problems were detected and the level of provitamin A in the grain was higher than that obtained in the greenhouse by the same lines.

The field trials with GR and the arrival of selected GR lines in Asia for introgression are recent major breakthroughs of the GR Programme. Approval will be sought on a country-by-country basis and will involve the completion of regulatory dossiers as required by national laws. It is hoped that most information contained in the regulatory dossier will be transferable from country to country, eg using the Biosafety Clearinghouse mechanism established by the Convention of Biological Diversity (CBD).

A number of factors affect the intestine's ability for provitamin A uptake from different foodstuffs. Carotenoids are often tightly bound to sub-cellular structures, thus a certain level of cooking usually enhances extractability; carotenoids are quite heat stable. In some foodstuffs carotenoids form insoluble crystals, as in carrots, thus high content is not necessarily a measure for nutrient supply. Further food processing takes place in the mouth and in the intestine, where the presence of fat in the diet increases uptake. The starchy rice endosperm is a simple food matrix, which also includes lipid membranes. Thus, bioavailability of carotenoids in GR is expected to be high.

While earlier versions of GR would have been able to provide only 50 percent RDI in conjunction with existing diets, a conservative calculation predicts that the latest GR version will be able to provide more than 100 percent RDI to people living in rice-based societies.

The last remaining hurdle before release of GR to smallholders is obtaining regulatory approval. A problem with present regulatory regimes is that they have made the approval of transgenic crops prohibitively expensive. Publicly funded projects are not in a position to bear those costs. Overly complex regulatory frameworks have been set up in many countries, supposedly to protect consumers. Extensive evidence from widespread production and consumption of GM plants indicates that no specific harm emanates from transgenic crops, while very clear life-threatening conditions arise from the lack of micronutrients.

The regulatory equation blows up the theoretical risk and ignores the real benefit. According to a World Bank analysis, gains from improved health will by far surpass farming gains, amounting to billions of dollars. Expected losses stemming from European import bans would amount to less than 0.5 percent of the projected gains (Anderson et al. 2004).

Hunger and malnutrition affect all developing countries. Providing a solution to VAD only addresses part of the problem. Multiple nutrient deficiencies, including lack of iron, zinc, iodine, and high-quality protein lead to a serious, worldwide problem. Therefore, we have now embarked in a multi-pronged approach to tackle this compound problem in a concerted fashion by making GR more micronutrient dense. A main objective of the new project is to generate rice lines harbouring multiple traits in a single genetic locus, to facilitate breeding into local cultivars.

Biofortification is progressing at multiple levels: multi-institutional, multicrop, multitrait, multistrategy, transgenic and non-transgenic. This task is being pursued by the ProVitaMinRice Consortium, led by the group of Peter Beyer of the University of Freiburg. The Consortium further includes groups from Michigan State University, Baylor College of Medicine (Houston, Texas), the International Rice Research Institute and PhilRice, in the Philippines, the Cuu Long

Delta Rice Research Institute, in Vietnam, and the Chinese University of Hong Kong. Three other projects funded through the Grand Challenges in Global Health Initiative of the Bill & Melinda Gates Foundation are following the lead of the GR technology. These projects are applying similar approaches to cassava, banana, and sorghum. Their common goal is to stack multiple traits together: carotenoid production, iron and zinc accumulation, vitamin E and high-quality protein production.

In sum, biofortification combining genetic engineering and traditional breeding offers a sustainable, non-intrusive solution to a life-threatening problem that affects millions of poor people, especially children, around the world.

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Economic Impacts of Genetically Modified Crops in Developing Countries

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This paper reviews the evolving literature on the impacts of genetically modified (GM) crops in the developing world. GM technologies that have been used so far in Latin America, Africa, and Asia include herbicide-tolerant soybeans, insect-resistant Bt cotton, and to a lesser extent Bt maize. The results provide a consistent picture: in spite of regional and temporal variability, average economic gains for adopting farmers are sizeable. In many cases, farm level benefits of GM crops in developing countries are bigger than those in developed countries.

Herbicide-tolerant soybeans do not reduce the amounts of pesticides applied. But they allow farmers to substitute an environmentally less damaging herbicide for more toxic products and to reduce tillage operations and labor time. This leads to significant savings in production costs. So far, herbicide-tolerant technologies have only been used in highly mechanized farming systems, especially in Argentina and Brazil. Whether or not they can also be advantageous for farmers who control weeds manually depends on seasonal labor availability in the local setting.

Bt technologies are different in nature, because they provide resistance to major insect pests. Adoption of Bt cotton has led to insecticide savings ranging between 30 and 80 percent. Moreover, significant yield gains have been observed in most developing countries, especially in situations where insect pest pressure is high and pesticide use is low. Different studies show that small and marginalized farms tend to benefit more than large ones, and that the technology works under diverse agroecological conditions. Bt crops also bring about favorable environmental effects. Pesticide reductions in particular are positive for flora, fauna, and farmers' health. Nonetheless, more research is needed into the complex interactions with natural systems, before conclusive statements about the sustainability of GM crops can be made.

Almost all GM crop technologies commercialized up till now were developed by the private sector, so that price premiums are charged on seeds. The scope for companies to set prices

above competitive levels mainly depends on the strength and enforcement of intellectual property rights (IPRs). Contrary to widespread beliefs, monopoly power in developing economies is fairly restricted. In many cases, farmers reproduce their own GM seeds, and also seed sales among farmers are common. Furthermore, farmers always retain the option not to adopt or to switch back to conventional seeds, when technology price premiums are excessive. The empirical evidence shows that farmers are the main beneficiaries of GM crop innovations so far. This is reflected in the rapidly increasing adoption rates. Nonetheless, the private sector primarily develops technologies for large lucrative markets. GM technologies that are specifically targeted to resource-poor farmers in developing countries are largely neglected. Such gaps need to be addressed through more public research and public-private partnerships.

The same holds true for GM crops that could improve nutrition effects for poor food consumers – such as staple crops bioengineered to contain higher amounts of micronutrients. Micronutrient deficiencies are widespread problems in developing countries – often with serious health consequences, especially among women and children. A well-known example of a GM technology which could address problems of micronutrient deficiencies is Golden Rice. Golden Rice contains beta-carotene, a pre-cursor of vitamin A. While this technology is still being developed and adjusted to developing-country conditions, it has already become a centerpiece in the public controversy over GM crops. Based on a summary of a comprehensive ex ante evaluation, it is shown that Golden Rice will not eliminate vitamin A deficiency completely. Yet, given sufficient public support, it can be an effective and efficient intervention to significantly reduce the problem in rice-eating populations. Apart from Golden Rice, other staple food crops with higher amounts of micronutrients are currently being developed.

GM crops are not a panacea for the problems of food insecurity and rural poverty. They should not be seen as a substitute for other agricultural technologies, nor for much needed institutional change in developing countries. But, as an ingredient in strengthened and pro-poor innovation systems, GM crops can contribute to farm income increases, agricultural growth, and nutritional benefits, as the empirical evidence demonstrates. Policy support is needed to minimize the technological risks and realize the potentials on a larger scale. This presupposes that the emotional debate is overcome and replaced by a constructive dialogue. Further studies should be carried out to analyze the secondary effects of GM crops in greater detail and provide policy advice for sustainable technology management.

Ensuring safe use of GMOs in the developing countries: The Cartagena Protocol on Biosafety

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With regard to genetic engineering there was from the very early stages a close relationship between basic research, biosafety research, regulation and product development. At the so called *Asilomar-Conference* (February 1975 in Pacific Grove, California) app. 100 leading scientists came to the conclusion that specific biosafety research should be performed to develop systems of biological containment and that guidelines should be developed for the safe use of genetic engineering. Those milestones on scientific responsibility have clearly imprinted today's legislation on genetically modified organisms (GMO). Following the setting-up of the so called *NIH guidelines* in 1976 in the USA, Germany developed similar guidelines in 1978 as did other EU member states. Since 1990 we have EU community legislation on GMO.

In 1995, the Parties to the Convention on Biological Diversity (Rio Summit, 1992) launched negotiations on a legally binding agreement that would address potential risks posed by GMOs. These discussions culminated in January 2000 with the adoption of the Cartagena Protocol on Biosafety. The Protocol for the first time sets out at UN level a comprehensive regulatory system for ensuring the safe transfer, handling and use of GMOs subject to transboundary movement.

The Protocol deals primarily with GMOs that are to be intentionally introduced into the environment (such as seeds, trees or fish) and with genetically modified farm commodities (such as corn and grain used for food, animal feed or processing.

The Cartagena Protocol promotes biosafety by establishing practical rules and procedures for the safe transfer, handling and use of GMOs with a specific focus on regulating movements of these organisms across borders, from one country to another. This system features two separate sets of procedures, one for GMOs that are to be intentionally introduced into the environment, and one for GMOs that are to be used directly as food feed or for processing. Both sets of procedures are designed to ensure that recipient countries are provided with the information they need for making informed decisions about whether or not to accept GMO imports. Governments exchange this information through a Biosafety Clearing-House and base their decisions on scientifically sound risk assessments and on the precautionary approach.

When a country decides to allow the import of a GMO, the exporter must ensure that all shipments are accompanied by appropriate documentation. Governments must also adopt measures for managing any risks identified by risk assessments.

During the negotiations process to reach consensus on the text of the protocol and the following phase of implementation and putting into praxis, it has become obvious the majority of the developing countries and the countries with economy in transition tend to follow the principles of the EU legislation on GMO in place.

The EU legislation on GMO sets out very high standards requiring very cost intensive measures for risk assessment, decision making, monitoring and enforcement. The EU legislation is further more not only driven to prevent risks but clearly bears also no risk related political driven elements.

Therefore it should be questioned whether the adoption of the EU approach on GMO is recommendable for developing countries and countries with economy in transition. The required measures to follow the EU approach could present the use of genetic engineering techniques for the specific needs of those countries even if possible risk which might be involved with the use of such techniques could be dealt with in a adequate way by standard safety measures of low costs.

La Recherche—Du Temps Perdu?
Successes and Continuing Challenges in Addressing Global Hunger and Malnutrition

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While food and nutrition crises continue to capture the media headlines, and an unacceptably large number of individuals around the world face hunger on a daily basis, there are nevertheless encouraging signs of improvement, many success stories, and much to be optimistic about for the future. The false dichotemy, that for several decades has posited no relationship between growing more food, on the one hand, and solving world hunger, on the other, is today being challenged. The role of food and agriculture (and by extension agricultural research) in overcoming hunger is critical, and, arguably, growing. The 'nutrition/health' and 'farm' lobbies have more to gain from collaboration than from competition for resources, and the benefits of cross-sectoral synergies for resolving malnutrition are huge. But only if the lessons of experience are applied quickly, at scale, and appropriately funded. Since none of these conditions currently apply, the world community continues to be faces with picking up the pieces after disasters and making do with under-funded public research endeavours. This has to change if the Millennium Development Goals are to be met.

Prof. Dr. Franz Heidhues

Food and Nutrition Security of the World: The Role of Biotechnology

Kolloquium anlässlich des 80. Geburtstages von
Senator e.h. e.h. Dr. Dr. h.c. Hermann Eiselen

Dear Senator Dr. Eiselen,
dear Mrs. Eiselen,
Ladies and Gentlemen,

With this symposium we are honoring

Senator Dr. Dr. h.c. Hermann Eiselen.

Dr. Eiselen was born 80 years ago im „Schwabenland" (Suebia), to be exact in Nagold, a rural town in the northern part of the Black Forest.

Prof. Steiner, last evening characterized the Suebian dimension of Dr. Eiselen's personality. He also said that I would address the international and development dimension of his work. I will try to do that in the next 10 minutes, but not without pointing out that the two are intimately interconnected:

Having experienced at the age of 16-19 years the horrors of war, the injustices and the misery, poverty and hunger that war brings along, this must have had a profound impact. You, Dr. Eiselen, mentioned last night also, that Prof. Josef G. Knoll made you aware that that situation of poverty and hunger was not limited to war-end and post-war Germany, but was an enormous problem world-wide. Perhaps the two experiences together go a long way to explain your devotion to the fight against hunger and poverty in the world.

Dr. Eiselen studied economics in Stuttgart and Heidelberg and did his Ph.D. in economics at the University Göttingen where he enjoyed the particular support of Prof. Isaak. The topic that he worked on in his PhD is today again of great relevance. It was dealing with the question: How to evaluate the assets of an enterprise for establishing the balance sheet after a monetary reform; at that time it was the introduction of the DM.

Today in transformation countries where socialist planning has been replaced by a market system, regularly accompanied by monetary reform, the new evaluation of enterprise assets is one of the most difficult problems to resolve. At the same time, it is a most important issue to resolve, as the privatisation of state enterprises is impossible to carry out fairly, if the value of enterprise assets is unknown.

Subsequently he stayed for almost a year in the United States and then joined the family enterprise “Ulmer Spatz Vater und Sohn Eiselen”. He founded together with his father the “German Bread Museum” that in 2000 became the “Museum für Brotkultur”, the oldest and internationally most reknown museum devoted to the history of bread and its meaning to human culture.
In 1978 he also founded the “Vater und Sohn Eiselen Foundation Ulm” which is devoted to the fight against hunger and poverty. It focuses on promoting food and nutrition security for all, through the support and funding of research, particularly agricultural research, and of education and training of young scientists working on these topics.

For his invaluable service in supporting agricultural research and education and promoting the understanding of –and sensitivity for- poverty and hunger, to which the “Museum für Brotkultur” importantly contributes, Dr. Eiselen received the highest honors and recognitions that to mention individually would go beyond the time allotted to me. Time also does not allow me to highlight all the highly appreciated activities of Dr. Eiselen. Allow me, however, to highlight three particularly important ones in the area of research and teaching support:

1. The programs of The Father and Son Eiselen Foundation Ulm

The Foundation has supported since its initiation research and teaching with a total amount of € 9 Mio.
This includes

- 160 research projects and research supporting activities, among them, the initiation and preparatory work for the University’s Special Research Program in South East Asia, generally called the Uplands Program. Without that generous help it is highly doubtful that it would have been possible to get the Uplands Program approved and on track.
- This includes the research program “Applied Genetics to the Benefit of World Food Supply” which the Eiselen Foundation supported between 1985 - 1996 with € 6 Mio. Yesterday and this morning we discussed this program’s major findings and achievements
- The Foundation also funded two major international symposia: one was the **1996 Hohenheim Symposium “Food Security and Innovations - Successes and Lessons Learned”**. Those of us who attended that symposium

remember the vibrant and inspiring presentation of Prof. Sir Hans Singer (at the time 85 years old). The name of Prof. Singer is known to every student of development economics. Studying the “Prebish-Singer Model” of a long-term decline of developing countries’ terms of trade is part of the standard diet for every student of economics. The second symposium was the **2002 Chiang Mai International Symposium “Sustaining Food Security and Managing Natural Resources in Southeast Asia: Challenges for the 21st Century”.** Leading scientists of different disciplines, among them the former head of the Ford Foundation, Prof Robert Havener, Prof Siamwalla of Thailand, Prof. Xuan of Vietnam, and others participated in that symposium.

- The Foundation also supported the **Diploma/Masters Scholarship Program**, under which 420 Dipl./Ms Theses with a total of € 750.000 were funded. This scholarship program is particularly valuable as it is a career development program preparing young scientists for a later career and work in agricultural and development research and development cooperation. There is an important feature that is shining through all your and the Foundation’s work, and that is the Suebian entrepreneur with the typical characteristics:innovativeness, efficiency, result orientation, monitoring results.

  The Foundation has resisted the general trends we observe everywhere towards increasing bureaucracy and filling in forms, and sheets and what have you. The application and approval processes are simple and short.

  The emphasis is on research that produces farmer relevant and applicable results.

  And: as beneficiaries of research support we are persistently reminded of documenting and submitting evidence of the results of our work.

  And that is good!

Apart from the Foundation activities supporting research and teaching there is

2. The Price / Award Program

- the “Josef G. Knoll Wissenschaftspreis” (awarded every two years) under which since it initiation in 1986 37 young scientists were awarded in total € 170.000
- the “Hans H.Ruthenberg Preis”, under which excellent Dipl./Ms Theses are awarded : so far (since 1999) 19 awards for a total of € 48.000

3. The Josef G. Knoll Stiftungsgastprofesssur

In addition to these programs that are supported by the Eiselen Foundation, the 3rd major activity is the "Josef G. Knoll Stiftungsgastprofessur for Development Research", privately funded by Dr. Eiselen. Also this program can look back at a proud record.

The first appointed professor to the Stiftungsgastprofessur was Prof. Patrick Webb, he is now Dean for Academic Affairs at TUFTS University`s School of Nutrition Science and Policy; he is , as you just saw, here among us

He was followed by Prof. Neubert, Prof. Korff and now Prof. Berger, all three active participants in the Uplands Program. It deserves emphasizing that this Stiftungsguestprofessorship was extremely successful:

All incumbents were called to become tenured professors (C4) at highly reknown universities. When Prof. Webb was offered to join TUFTS University Dr. Eiselen was a bit sad to see him leave. Two comments I would like to add here:

(i) better being sad than the opposite

(ii) the Stiftungsgastprofessur did a very valuable service to development research and teaching in general; it helped to attract a very talented scientist, who at the time was working for an international organisation, back into science and academia. And that is no small achievement.

In summarizing

Some of us may ask:

What has been the impact of these support programs on the hunger and poverty situation in the world?

Given the vast magnitude of the problem that question may be difficult to assess quantitatively. But two aspects suggest that the program is highly effective. They deserve emphasis:

The Eiselen Program is focussed on the two most important ingredients of development

- human capital formation, i.e. education and training; and
- production of knowledge, i.e. agricultural research, particularly for the poor. And

particularly the poverty focus means it is very rightly focused.

We know from recent research of IFPRI and others that the rates of return of this research are high and, by the standards of development cooperation , even very high (40 - 85 %). We also know, that research investments in poor areas have rates of return, as high as and in many cases even higher than those in high potential areas.

Let me conclude in stating that the Eiselen Foundation and you, Dr. Eiselen, can look back at a highly valuable and successful support program. The task of fighting hunger and poverty is so enormous that it requires many steps and initiatives. We are grateful that you took the initiatives and translated them into action.

We are happy to see that you found Dr. Fadani, by the way a Hohenheim product, to continue your Foundation's work, and we are sure that with his competence, motivation and leadership - as we expect it of Hohenheim's top graduates - will guide the Foundation in your sense and interest.

Herr Dr. Eiselen, Frau Eiselen, we wish you for the coming decade all the strength, energy and health to continue your invaluable work, and we hope that your example will find many more followers in the future.

Thank you.

Dr. Dr. h.c. Hermann Eiselen, c/o Eiselen-Foundation Ulm, Germany **11. May 2006**

The importance of plant biotechnology to improve global food security

Ladies and Gentlemen

It is a great honour and an important experience for me that this colloquium was dedicated to me. Let me express my sincere gratitude especially to Prof. Weber who had this idea and made it work. I also thank all friends and participants some of whom have travelled a long way to share their views on problems of great concern to all of us: The vision of a hunger free world. As I am a protagonist of Green Biotechnology for more than 20 years Prof. Weber has asked me to give you my personal view. I shall try to do so very briefly, being well conscious that this is more a wood cut than a copper engraving. And it is neither scientific nor does it contain anything new.

1. World population is increasing rapidly, mostly in those regions where food deficit is predominant already now. Estimates range between 50 and 80 percent compared with today. In large countries like China consumption moves toward more refined food which means higher demand of basic agricultural products per capita. In 64 out of 105 developing countries population growth exceeds increase of food production.

2. At the same time the agriculturally usable land is shrinking by several reasons commonly known. In figures: 1960 availability of land was 0.44 ha per person, today 0.24 ha with tendency to further reduction. Water resources are shrinking. In many regions of the world the present levels of irrigation are not sustainable, a further retrenchment for agriculture.

3. The bottom line of those undisputable facts is: The word must produce more food on less land. In other words: Productivity of the remaining land must be increased almost beyond our imagination. Many say beyond all realistic chances. And this must be accomplished in regions where food deficits prevail and where conditions are not

favourable. The challenge is truly immense By the way: I am strongly opposed to the widespread opinion claiming there is enough food for all and it simply must be distributed properly. I don’t want to elaborate on this issue but just want to say: If the solution were that simple, it would certainly have been implemented since at least five decenniums.

4. What are options to meet the Challenge? Firstly it seems to me that traditional and conventional potentials to increase agricultural production and productivity are not exhausted yet, namely for example:
   - agronomic techniques, such as non-tillage,
   - more efficient methods of irrigation,
   - terracing sloping land, and
   - intensification of land utilisation and cultivation,

   and similar methods as long as their application is environmentally sustainable which is absolutely crucial.

   Governments of food insecure countries should urgently improve the basic conditions for farmers. And the industrialized countries should ultimately change their trade policies towards the poor countries.

5. It is widely acknowledged that all those measures are not sufficient to solve the problem. One of the few remaining additional chances is the development of better seeds by using the new methods of biotechnology. To be more precise gene technology aided plant breeding. We have seen already to what extent the yield of plant production inputs can be increased. Further progress can be expected. Just a few examples:
   - resistances against many biotic and abiotic stress factors
   - increased photo synthesis efficiency
   - possible future nitrogen fixation
   - higher nutritional value of food plants

   It is still a young science and yet only a few of its vast chances so far have been utilized. A great advantage in any event is the gain of time compared with conventional breeding methods. This factor is of highest importance looking at the speed of population increase. The potential of plant biotechnology is more than evident. While so far modern plant breeding was

targeted to only one characteristic more multiple or complex objectives can be expected. The new technique will also be used to overcome plant immanent physiological constraints. Ecological or biospheric obstacles preventing improvements of seed properties will be eliminated. Salt tolerant plants could regenerate over salted soils in the future. Herbicide resistant plants will enhance IPM methods. Last but not least genetically modified plants will further reduce the use of chemicals and thus prevent health hazards. Those perspectives are in reach and a veritable reason for hope.

6. Unfortunately so far the seed industry was the pacemaker of the accomplishments. It preferably worked in areas where research promised swift success. These expectations have come true. Genetically modified plants are cultivated on 90 million hectares today. The tougher nuts however still have to be cracked. And this should happen in research institutions outside the industry in order to ensure that the results are freely available to all farmers at reasonable prices. In other words: Research funded by the public or the non profit private sector is indispensable, but very delicate because of public opinion. Even the CGIAR System which operates around the world and which is considered as independent dedicates a mere 7 percent of its funds to biotechnology. The “Golden rice” is an encouraging but so far singular example for successful publicly funded research. But the private non commercial sector alone is

unable to close the gap. Here we face a very serious unsolved problem.

Accomplishments of green biotechnology so far have bypassed the needs of about 500 millions smallholder farmers operating under unfavourable conditions such as low inputs and sensible environment, whereas the advantages of better quality seeds just for them are quite obvious: No capital investments, no overuse of soil, savings by reduction of pesticides and herbizides, higher yields per hectare, more income – all without negative side effects. Therefore in order to reduce the widespread rural poverty and improve the livelihood of hundreds of millions of people in many parts of the world we should feel responsible to give benefit of the new technology to them.

7. Economics of green biotechnology seem to be in favour of it. But so far experiences could be gathered only at large scale use of genetically modified seeds. Studies on transgenic cotton indicate that farmers' profits rose despite higher seed costs. These findings are in no way representative particularly not for small scale operations. Therefore it is much to early to judge economical impacts particularly on small scale use. Furthermore the costs are greatly influenced by the kind of supplier, whether the seeds are patented or not.

8. Every new technology comprises its risks. This is also true with regard to the new plant breeding techniques. The ecological impact of using genetically modified seeds is by far not clear enough and requires future intense and more systematic research. Again: Roughly 25 years of research are much too short to accurately assess the effects. And we must not forget that dangers and negative effects could become visible with delay only and may be irreversible. Those factors make it difficult to decide whether or not the new technology should be applied. The current state of research suggests that the use of transgenic plants can influence biodiversity in two directions, namely
   - undesired reduction of number of species
   - unintentional creation of new types of plants. Here it is not clear yet whether this danger – if it is one – is higher than it always has been during the evolutionary process. This is a point which should be kept in mind.

   As far as human health as the most important risk factor is concerned it looks to me that inspite of intensive worldwide search for health hazards caused by consuming transgenic plants or products thereof have not been proven, not even been found. So from today's standpoint food products from those plants can be regarded as safe. consequently the fearmaking of certain opposed people must be regarded unjustified. Nevertheless scientific vigilance is recommendable.

9. Green Biotechnology must not be considered a remedy of universal effect. It is only one among all other means to fight hunger and poverty. It is understood that the new technique must be used in full ethical responsibility. All scientific findings have to be made public whether positive or negative.

10. Much has been said and written mostly about the <u>risks</u> of green and other biotechnology. Hardly anyone ever considers the dangers caused by <u>not</u> using the scientific achievements. The real question is, whether it can be justified to allow hundreds of millions of human beings to go hungry or many millions of children starve to death at the same time as we have a tool in our hands which can alter this situation. Never in history progress was riskless. Progress needs a certain amount of responsibly applied courage.

So: Weighing the chances and risks of Green Biotechnology against each other, the scale is lowering to the side of using the new technology. This appraisal should continuously be monitored in the light of new scientific findings. If in doubt <u>I</u> would decide in favour of those innocently starving millions of fellow women and men. This is my confession.

Thank you.