

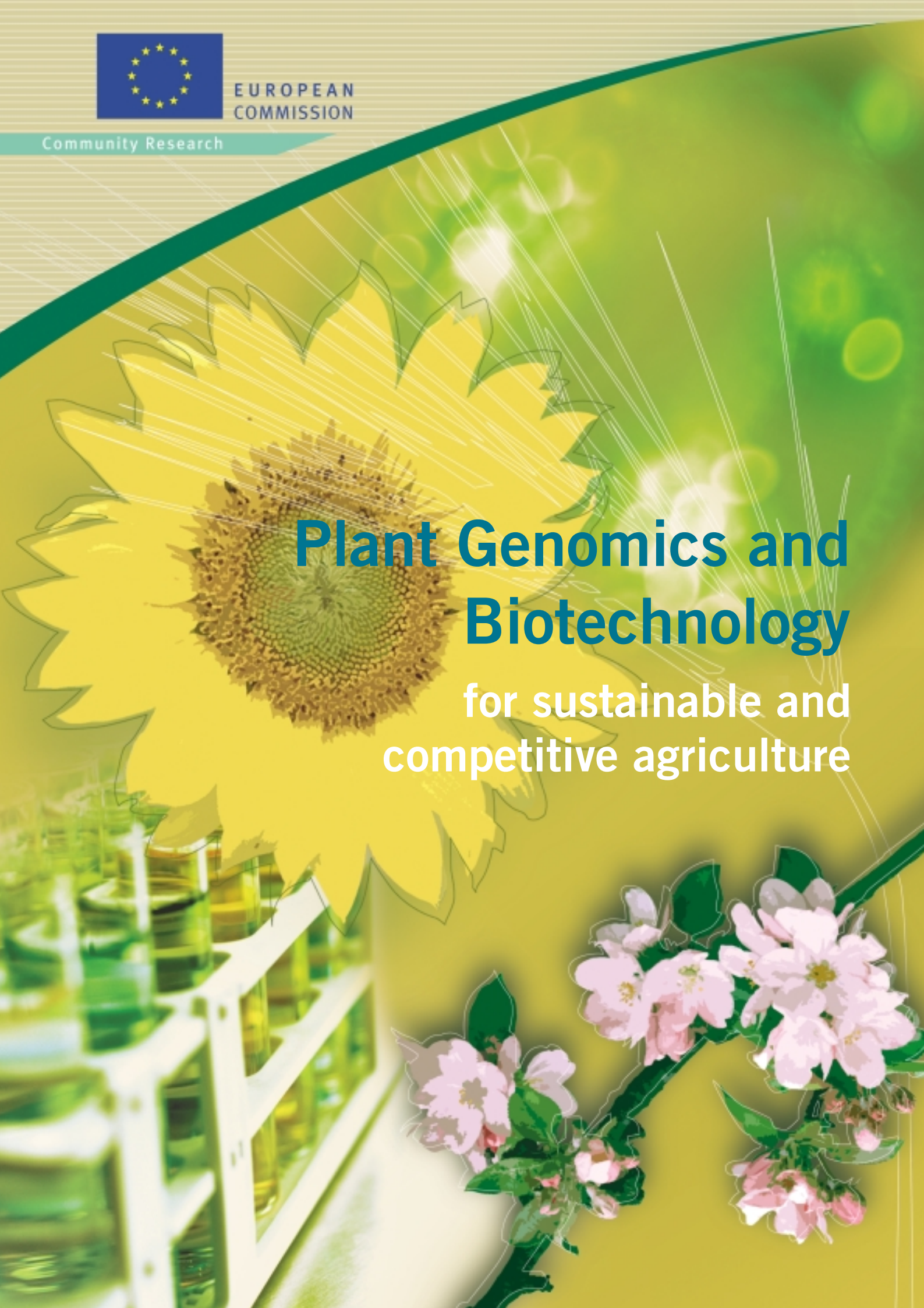


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EUROPEAN COMMISSION

Plant Genomics and Biotechnology

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Foreword



Plant genomics has become a rapidly developing field which is radically improving our understanding of plant biology while making available fantastic tools for the improvement of plant properties relevant to sustainable agricultural production, human and animal nutrition, as well as to non-food uses of plant products. The sequencing of the genome of the model plant *Arabidopsis thaliana* (2000), which was carried out by an international consortium with the support of the European Commission, was a milestone in plant genomics research.

Funding for plant genomics research and biotechnology has seen major increases worldwide over several years, and the European Commission's Framework Programmes are no exception. For example, within the Thematic Priority 5 "Food Quality and Safety" of the Sixth Framework Programme (FP6), the European Commission is supporting a major project on the improvement of grain legumes for food and feed, which involves participation in an international project sequencing the genome of the model legume *Medicago truncatula*. In addition, FP6 is supporting new initiatives on plant genomics. For example, EU plant genomics research will be coordinated and integrated progressively by a new ERA-NET initiative for national research programmes; and a long-term vision and means for its implementation will be developed by a Technology Platform on plant genomics and biotechnology planned for June 2004.

In response to this rapidly moving field, the Directorate-General for Research organised a meeting recently to review the state of play of ten research projects in plant genomics and biotechnology funded under the Fifth Framework Programme, to present the opportunities offered by FP6 and to encourage a discussion on the present status and future of plant genomics and biotechnology in Europe. Society includes a range of important stakeholders in the technology and, in recognition of this, ethical, legal and social issues of the use of such biotechnology are addressed by Strategic Support Actions in FP6.

This publication reports on the meeting held in Brussels on 27 November 2003 and, as well as offering an overview of the research projects themselves, also describes the priorities the participants identified as of immediate and fundamental importance to Europe. This comes at a crucial time and, I believe, provides a significant basis for the further development of plant genomics and biotechnology in Europe.

Christian Patermann

*Director of Biotechnology
Agriculture and Food Research
Research Directorate-General
European Commission*

Plant genomics and biotechnology for sustainable and competitive agriculture

European Union policy-makers are aware that science and innovation are keys to achieving sustainability and competitiveness in diverse economic sectors. Accordingly, the European Commission (EC) has adopted an Action Plan for increasing investment in R&D to 3% of the GDP by 2010, with two-thirds coming from the private sector. Europe is also intent on achieving optimal integration and Europe-wide coordination of research and on strengthening the collaboration between academia and industry, and between science and society. This is what building a European Research Area (ERA) is all about.

Plant genomics and biotechnology

Agriculture is a major economic sector which impacts on many others: food, textiles, chemicals, energy, health and medicine, and so on. Since it deals with living organisms and both exploits and shapes the environment, it relies heavily on progress in the life sciences and biotechnology.

Some of the most exciting prospects for innovation in agriculture concern crop plants. New developments owe much to the study of DNA (deoxyribonucleic acid), the material bearing the 'instructions' that determine an organism's inherited features. These instructions are 'written' in chains of 'letters' called nucleotides, forming 'words' called genes. Most genes code for proteins that play a structural, catalytic, or regulatory role. An organism's DNA is its genome.

About 30 years ago, scientists learned to 'cut-and-paste' segments of DNA and to clone isolated genes. This led to an explosion in discovery and technology development. Soon companies were selling 'genetically modified' plants expressing imported genes. Later, the (successful) endeavour to sequence the entire human genome prompted international consortia to tackle other genomes, such as that of the 'model' plant *Arabidopsis thaliana* and the crop plant rice – these sequences are now complete. Today, genomics is yielding a treasure trove of data that scientists have begun to exploit – plant genomics and biotechnology are revolutionising both plant science and agriculture.

Taking action

On 27 November 2003, the EC hosted a Workshop on Research in Plant Genomics and Biotechnology funded under Key Action 5 sub-area 1.1 (KA5.1.1 - Sustainable Agriculture) of the Thematic Programme 'Quality of life and management of living resources' of the Fifth Framework Programme (FP5). The aim was to see how the EU can capitalise on past and ongoing research and on the new opportunities being offered by the Sixth Framework Programme (FP6). Participants included coordinators of both ongoing KA5 and newly selected FP6 research projects alongside representatives of the FP6 Priority 5 'Food Quality and Safety' Advisory Group, representatives of EC services, and stakeholders. This brochure presents the main points of their presentations and the discussions which followed.



Workshop highlights



The Workshop was divided into three main areas: presentations of ten KA5 projects; an assessment of current EU plant research and FP6 opportunities; and a round-table discussion.

Diversity

Key Action 5 sub-area 1.1 (Sustainable Agriculture) is supporting 32 projects related to plant genomics and biotechnology. The ten presented at the Workshop were chosen from among those which have begun to yield results. The projects tackle a wide range of problems, from crop improvement (yield, vigour, plant architecture, flowering time, etc.) to plant health (host-pathogen interactions, disease resistance and pest control, diagnostics and food safety), genetic resources (characterisation, conservation and use), and the impact of GM crops (ecological, economic, and ethical).

Fragmentation and bottlenecks

In the past, EU plant research has been handicapped by fragmentation, and notably by a lack of coordination between national programmes and funding agencies. The basic requirements for such research include fundamental knowledge, networks of expertise, integration of different disciplines, and the development of bioinformatics. Genomics, in particular, needs both funding and integration because it is what is known as a 'big science' (capital intensive scientific research involving large teams of researchers and large facilities). Current bottlenecks include access to emerging technologies, a lack of EU-level strategic planning, and the ongoing public debate on the socio-economic and ethical issues linked to the use of genetically modified organisms (GMOs) in agriculture. The EC is intent on eliminating these constrictions, in keeping with its Strategy and Action Plan for Life Sciences and Biotechnology¹.

(1) http://europa.eu.int/comm/biotechnology/pdf/policypaper_en.pdf

Building ERA and FP6

FP6 is a new phase in ERA-building, and has been endowed with new instruments to facilitate the challenge – Networks of Excellence and Integrated Projects. These instruments are characterised by their capacity to mobilise the critical mass of expertise and know-how needed to achieve the Research Programme's ambitious objectives.

Plant genomics and biotechnology occupy an important place in FP6, mainly in Priority Areas 1 (Life Sciences, Genomics, and Biotechnology for Health) and 5 (Food Quality and Safety). 'Grain Legumes', which was presented at the Workshop, is an example of an Integrated Project selected from the first calls for proposals in FP6. Participants also learned about a plant genomics ERA-NET and a future Technology Platform for plant genomics and biotechnology.

GMOs: a new generation?

In a concerted effort to make progress in the GMO debate, the EC has established a GMO Safety Round Table. In the meantime, scientists have also been busy developing measures such as:

- **using a transferred gene to accelerate conventional breeding, then eliminating it before commercial use of an improved variety;**
- **'clean vector' technology (eliminating non-payload imported DNA);**
- **modifying plants with variants of their own genes and/or regulatory sequences;**
- **introducing the payload gene into a plant organelle that does not disseminate through pollen flow; and**
- **altering the flowering time of a GM plant so that it cannot cross-pollinate with nearby non-GM cultures.**

Thus, a new generation of GMOs is emerging which, it is hoped, will prove more readily acceptable to European citizens.

Foresight on EU plant science



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Plant science is key to making progress in agriculture. In the past, this was demonstrated by the Green Revolution, with its staggering increase in crop yields. Today, plant genomics and biotechnology are generating invaluable tools and a broad knowledge-base for applications in areas as diverse as crop improvement, food and feed safety testing, disease and pest control, the monitoring and management of biodiversity and genetic resources, and environmental protection and remediation.

To make the most of what plant science has to offer, Europe needs to coordinate its research effort and develop a long-term research strategy. This was the message of the European Plant Science Organisation (EPSO) chairman Dr Marc Zabeau in his presentation, the main points of which are summarised here.

Paradigm shift

The exciting new opportunities offered by plant genomics and biotechnology have emerged in parallel with a paradigm shift in these fields. The

'old' biotechnology strategy was to isolate potentially useful genes, transfer them into commercial lines, and express them there. The new strategy is to make an inventory of all the genes in an organism, study their expression profiles, roles and regulation, and then apply the basic knowledge gained to improve agricultural species through conventional breeding and/or genetic modification. This effort began with a few 'model' organisms. The first plant genome to be sequenced was that of a small weed called *Arabidopsis thaliana* (thale cress), chosen because it is a classic model in plant research, and is readily amenable to experimentation. In the meantime, the complete rice genome sequence has also become available, and others are bound to follow. Genomics today is 'big science' requiring substantial funding and an unprecedented coordination of research efforts, particularly at European level.

Strategy called for

One major obstacle here is that European research in plant genomics is much too fragmented, with little or no coordination among funding agencies or national programmes. Fragmentation is also apparent in the heterogeneity of skills and competences in genomics research among different European countries.



Other limitations are also playing a part: access to emerging technologies developed primarily in the US, a lack of strategic planning and commitment at the European level, and the wide-ranging debate on socio-economic and ethical issues (GMOs; environmental protection, and conservation of biodiversity vs. agricultural production).

To be truly competitive, Europe needs a strategy for plant genomics and biotechnology. This should include organisational measures, structural changes, and development of a long-term research agenda. It is necessary to organise, through European Networks of Excellence, internationally competitive large-scale projects for the implementation of genomics in a broad range of species that are relevant to agriculture. These networks must have appropriate infrastructures for high-throughput biology and strong bioinformatics centres. And the long-term research agenda should be based on a 20-year vision of EU plant science and agriculture.

Europe is aware

Both the European scientific community and the EC realised the need for such a strategy early on, and they have not been idle in trying to achieve it. The year 2000 witnessed a wealth of significant events:

- **The launch, by Research Commissioner Philippe Busquin, of efforts to build a European Research Area;**
- **The EPSO ten-year vision paper, written in response to the ERA endeavour. This paper formulated explicitly the need to devise a strategy for plant genomics and biotechnology;**
- **An EC-hosted workshop on Genomics and Post Genomics Agricultural Research in the ERA (Bordeaux, October 2000) defined a roadmap and the funding requirements for plant genomics in FP6;**
- **In December 2000, plant genomics was recognised as a key priority at the milestone EC-sponsored Versailles Conference, 'Agricultural Research in the European Research Area'.**

Looking forward

Hopes were high among plant scientists as FP6 began to take shape, with its new instruments and incentives to overcome fragmentation.

Unfortunately, the political climate was dominated by the GMO debate, and this was perceived as overshadowing plant science.

Despite this setback, room has been made for plant genomics and biotechnology in FP6 – European plant scientists have demonstrated the ability to think in terms of integration and networking, and several proposals have passed the selection hurdle. In addition to research projects, an ERA-NET and a Technology Platform for plant genomics will soon be laying new foundations for the future (see <http://www.epsoweb.org/catalog/index.htm>)

Dr Zabeau concluded by saying: "In the past few years, plant genomics and biotechnology have made considerable progress towards achieving desperately needed European integration and contributing to the EU's policy goals of sustainability, competitiveness and international development. Structures are being set up to ensure the sustainable future funding of plant science based on a long-term European strategic plan. We expect the first tangible results in FP7, but we must continue to push the agenda!"

New instruments in FP6

Instruments for research in the Priority Thematic Areas:

Integrated Projects (IP): IP are designed to meet societal needs and enhance EU competitiveness. Focusing on an ambitious goal, an IP combines all the expertise, technology, and activities needed to reach that objective.

Networks of Excellence (NoE): offer the durable integration of research capacities and restructuring and reshaping the way research is carried out in Europe.

More "traditional" instruments, similar to those used in FP5, such as 'Specific targeted research projects' (STREP), 'Co-ordination actions' (CA) and 'Specific support actions' (SSA) remain in FP6, thus providing an element of continuity between Framework Programmes.



Opportunities in FP6

The EC has been supporting research in plant biotechnology for over 20 years, from the start of the Biomolecular Engineering Programme (BEP) in 1982. BIOTECH II (1994-98), for example, supported 42 projects in plant biotechnology, a European Plant Biotechnology Network, and a European consortium which made a significant contribution to the *Arabidopsis thaliana* genome initiative.

From the first Framework Programme right up to FP6, the budget share devoted to the life sciences has increased steadily, as has the emphasis on networking, integration, and coordination, embodied in the ERA concept adopted in 2000. Today, FP6 (2002-2006) is deploying a wide range of instruments to help make the ERA a reality (see box page 7).

FP6 and plant science

Speaking at the Workshop, Dr Guillermo Cardon of the Commission's Directorate-General for Research commented that plant scientists are becoming increasingly integrated into projects that do not focus exclusively on plants but that are more interdisciplinary, often covering the whole food and feed chain or production, processing and applications of other plant-based products. He acknowledged that there is no specific 'single entry point' for plant genomics and biotechnology in FP6, but showed how these disciplines actually fit into the scheme.

FP6's **Integrating Research** supports research in seven 'Priority Thematic Areas'. Projects involving plant genomics and biotechnology should find a place either in Priority 1 (Life Sciences, Genomics, and Biotechnology for Health), Priority 5 (Food Quality and Safety), Priority 3 (Nanotechnology, Intelligent Materials, and New Production Processes), Priority 6 (Sustainable Development and Global Change), or the so-called 'Priority 8' (Research for Policy Support).

Other parts of FP6 may also attract plant scientists:

- **Integrating research/Cross-cutting research activities:** Anticipating scientific and techno-

logical needs, Specific SME activities, and Specific international co-operation activities;

- **Structuring the ERA:** support for developing research infrastructures and promoting the development and mobility of human resources; and
- **Strengthening the foundations of the ERA:** funding initiatives aimed at enhancing the coordination of research activities.

Health and food

Agriculture, the life sciences, food, and health are intimately linked. Consequently, Priorities 1 and 5 are privileged areas for research into plant genomics and biotechnology.

Thematic Priority 1, Life sciences, Genomics, and Biotechnology for Health aims to help Europe exploit the genomics revolution to the benefit of public health, citizens, and the European biotechnology industry. In particular, the basic research involved can concern plants in areas such as comparative genomics and population genetics, functional genomics of basic biological processes, new diagnostics and therapeutic tools, and innovative research in 'post-genomics' (generating biological knowledge from the genomic data). In addition, technologies developed in structural genomics, gene expression and proteomics (the study of the proteins encoded by genes), and bioinformatics may impact on plant research and agriculture.

The objectives of **Thematic Priority 5, Food Quality and Safety** are to ensure the health and well-being of European citizens through a better understanding of the influence of food intake and environmental factors on human health, and to provide European citizens with high-quality and healthy foods. Here the EC has adopted a 'fork-to-farm' approach in which consumer protection is the main driver for research likely to lead to improvements all along the food production chain. SME participation is strongly encouraged in Priority 5 projects.

Research in Priority 5 will focus on topics as diverse as food-related diseases and allergies, environmental health risks, the impact of food and animal feed on health, traceability along the food chain, safer and environmentally friendly production methods and foodstuffs, the production of higher-quality food raw materials and nutritious foods, the improvement of farming and production systems, and the comparative assessment of their safety,



quality, environmental impact, and competitiveness aspects. The tools and knowledge stemming from research in genomics and biotechnology are likely to make a tremendous contribution in most of these areas, and the first harvest of projects and initiatives looks promising.

Integrating research

Expressions of interest received during the FP6 preparation phase contained a wealth of ideas and suggestions from plant scientists, although not all of them passed the hurdle of selection for inclusion in the Priority 5 Work Programme. The Integrated Project 'Grain Legumes' (<http://www.eugrainlegumes.org>), presented at the Workshop by Dr Noel Ellis (John Innes Centre, UK) illustrates just what it takes to be successful in the proposal selection procedure: the right blend of expertise, an integrated vision, a well-structured implementation plan, and high relevance to EU policy.

Grain legumes (GL) are plants of the 'pea family'; examples include many plants of agricultural interest such as peas, lentils, beans, chickpeas and lupins. These plants are notable for the high protein content of their seeds and for their association with bacteria capable of fixing atmospheric nitrogen. They are used for both human food and animal feed and, when grown in rotation with other crops, they leave a nitrogen-enriched soil for the next crop, thus reducing the need for fertilisers.

The ambitious goal behind Grain Legumes is to promote the use of GL in EU agriculture and industry. Currently, because the EU has to import about 70% of its plant protein, the European Parliament's Agriculture Committee advocates exploring the potential of GL as an alternative protein source. Unfortunately, EU farmers hesitate to plant GL because of unreliable crop yields, and there is a need to develop ways of incorporating these grain legumes into animal feed. So, an IP addressing these problems is very topical and timely.

The project is organised in eight interacting modules. Seven of them span the entire range from lab to end-user: genetic and genomic tools, bioinformatics, seed quality, crop performance, feed use, economic and environmental impact, and a 'dissemination and technology transfer' module liaising with a platform of commercial end-users.

Among the new genetic and genomic tools to be developed for grain legume improvement it is important to highlight the contribution of the IP to the complete sequencing of the gene-rich regions of the *Medicago truncatula* genome (a model legume) within an international project. The eighth module organises training in emerging technologies and the dissemination of results. With 54 partners (over 60 labs and six SMEs) in 18 countries, Grain Legumes is on the way to building a European area for GL research.

Widening the net

Another recently launched initiative is ERA-PG, the ERA-NET for Plant Genomics (<http://europa.eu.int/comm/research/press/2004/pr3001-2en.html>). At its core are five national programmes that have already engaged in bilateral or trilateral co-operation. ERA-PG aims at improved coordination of national/regional plant genomics research programmes to develop the common knowledge base necessary for the coherent development of policies and the structure to use the limited resources available as efficiently as possible. Long-term perspectives are the improved validation of RTD strategies, the optimisation of the huge investments required for plant genomics research and the support of EU policies with respect to competitiveness, and a co-ordinated response towards common European challenges. At its launch, ERA-PG counted 11 partner countries (ten Member States and Norway), and at least nine more countries are expected to join. This ERA-NET has already had a structuring effect: some countries with no previous plant genomics research programmes have now set one up in order to be able to participate.

ERA-PG activities include meetings between EU programme-makers and managers (with short-term exchanges of programme managers and preparation of a joint database of experts and advisors), exchange of best practices, vision-2015/2020 meetings and position papers, the development of common electronic communication tools, and preparation and implementation of cooperation agreements.

The network's work packages reflect its strategy: to develop exchange of information, to formulate strategic actions, to implement those actions, and to begin to structure the future.

Topping the agenda

Presentations of ten KA5 projects proved to be a high point in the Workshop. Outlines of these projects are given below, illustrating their contribution to crop plant improvement, plant disease control, preserving and exploiting biodiversity, and evaluating the impact of GM crops. For further details see pages 15-26.

Optimising tomatoes

Focusing on greenhouse tomatoes, the **OPTIMIZE** project aims to get the best from plant features that influence light penetration, the amount of manual labour required, tomato yield, disease spread, flowering time, size and ripening homogeneity, and fruit taste and health benefits. The research combines genetic engineering (applied to tomato genes) with analysis of mutant and transgenic plants. Plants with altered leaves and tomatoes showing extremely high levels of health-promoting antioxidants are among the exciting results obtained to date.

Timed flowering

In the **CONFLOW** project, partners are developing genetic tools for the control of flowering. The objectives are to optimise the flowering time in agriculturally important crops, to shorten the juvenility phase of forest and fruit tree breeding lines (so as to enable conventional breeding), and to facilitate containment of GM crops (and hence, their coexistence with non-GM crops) by (reversible) inhibition of flowering or its timing, so as to avoid cross-pollination.

Growth and vigour

The **GVE** project aims to understand plant responses to the environment, to identify genes and pathways that control plant vigour in the model plant *Arabidopsis*, to assess candidate master regulators by genetic modification of *Arabidopsis*, and to validate the findings in rapeseed and rice. The results should lead to the development of conventional breeding or GM strategies for increasing crop-plant vigour and yield under restricted environmental conditions.



Biodiversity and gene banks

The **TEGERM** project is developing genomic tools for characterising and exploiting the genetic diversity of plant genetic resources stored in agricultural gene banks. The study relies on the genetic variability generated by retrotransposons – DNA segments that alter an organism's DNA sequence by inserting themselves into it permanently. It involves selecting retrotransposon markers and developing high-throughput retrotransposon-based marker systems. These systems will then be used to characterise the genetic diversity of major EU and international germplasm collections and to assess their use in extracting traits from germplasm into breeding materials.

Disease detection

The **DIAG CHIP** project is investigating the feasibility of producing a single diagnostic chip for the simultaneous detection of all plant pests and pathogens listed in the EU Plant Health Directive.

Fungus-resistant rice

Focusing on those rice varieties grown in Europe, the **EURICE** project aims to generate the knowledge needed to tailor new rice cultivars with enhanced resistance to fungal attack. The research involves engineering rice plants to express one or more defence genes, challenging the plants with fungal pathogens to assess their resistance, studying plant-fungus interactions, and evaluating transgenic lines in field trials. Special attention is being paid to avoiding gene flow from GM to non-GM plants.



Virus-resistant vines

The objective of the **RESISTANCE IN GRAPEVINE** project is to create a GM grapevine and rootstock showing durable resistance against viruses. The research is based on an exciting idea: to engineer plant cells to produce active fragments of chicken or mouse antibodies targeting key viral proteins. The project has already yielded tools for detecting viruses in plant tissues and for analysing viral spread and virus infection cycles. The first GM grapevines expressing virus-targeting antibody fragments should be available for analysis in the first half of 2004.

No access – no food

The **NONEMA** project is studying parasitic worms (nematodes) that attack crop plants, the aim being to engineer broad and durable resistance against such parasites. The approach involves identifying crucial elements in plant-nematode interactions and exploiting the knowledge gained in order to hinder either parasite access to plant cells or parasite feeding. Partners have identified a dozen nematode pathogenicity factors and several plant genes involved in parasite feeding, and a promising strategy to specifically knock out pathogenicity factors is now under development.

GM strawberries

The major aim of the **TSP-EEES** project is to develop GM strawberries resistant to grey mould. The idea is to over-express an element of the plant's own antifungal defence system. In parallel, project partners are addressing the socio-economic

and ethical issues linked to placing such strawberries on the market. In particular, they are questioning producers and consumers, listing risks and uncertainties, and seeking to translate the precautionary principle into practical guidelines.

Crop evaluations

The **ECOGEN** project combines an economic assessment of GM crops with a study of their impact on the soil ecosystem. The ecological analysis includes lab tests on isolated soil organisms and model ecosystems, and field tests comparing conventional and GM crops. Once all the data have been integrated, the idea is to develop scenarios with different crop rotation sequences to see what will happen as regards the soil and the economy.



Sharing expertise

The plant genomics and biotechnology projects in KA5 represent a diversity of expertise and a wealth of early experience in ERA-building. The FP6 managers were eager to tap this source in order to ensure optimal targeting of Thematic Priority 5, Food Quality and Safety. The Workshop's final round table, which is summarised below, offered a unique opportunity to do just that.

Research and sequencing

During the project presentations and round-table discussion, scientists stressed the importance of **basic research** in plant science. If we want to adjust plant physiology thereby countering major crop diseases while protecting the environment and maintaining biodiversity, we need to understand their underlying life processes and interactions. Several workshop participants hailed **systematic genome sequencing** as a resource-efficient way of gaining this much-needed information. For example, the tomato is the 'flagship' of the *Solanaceae* family, the most important cash-earning crop after cereals. At present sequencing of the tomato genome is being carried out mainly in the US and therefore workshop participants stressed the importance of Europe becoming part of an international tomato-sequencing consortium. They suggested that part of the funding needed could come from an Integrated Project on the *Solanaceae* within Thematic Priority 5, Food Quality and Safety, aiming at the improvement of the nutritional quality of Solanaceous vegetables (tomato, potato, pepper, eggplant and others). Such a project would benefit greatly from the availability of *Solanaceae* genome sequences. Consequently, the participants recommended the inclusion in the Priority 5 work programme of a topic on Solanaceous vegetables. Several researchers called for EU support for other key sequencing projects as well.

GMOs: a broader context

The discussion highlighted the need to look at GMOs more broadly. One scientist commented: "Consumers don't realise how much their food has been manipulated by conventional techniques. Nor

is the public aware that GMOs offer the possibility of biological, rather than chemical control of plant diseases. This means reducing the harmful health and environmental effects of pesticides." Other observations included: "GM plants are just another impact factor. We need to examine and compare the environmental and health impacts of different agricultural systems and practices."

"If we are interested in environmental impact, the emphasis should be on all environmental impacts, not just GMO containment." In addition, some participants stressed that GMOs should be assessed on a case-by-case basis, taking into account not only the specific risks *but also* the benefits of each GMO as well.

Important messages

Because it is essential to move beyond a sterile polarisation of the GMO debate, most KA5 projects dealing with transgenic plants already include informing the public among their activities. This trend will be reinforced in FP6, as illustrated by the following measures:

- **Education of and interaction with the public is a necessary component of each Integrated Project;**
- **The ERA-Net scheme also addresses science and society; and**
- **A Plant Genomics Technology Platform will bring together a wide range of stakeholders to discuss all aspects of relevant biotechnologies.**

One message which rang out loud and clear during the round table is that both policy-makers and scientists are responding constructively to public concern about GMOs in food and agriculture. Regulators are developing a legal framework that puts the emphasis on human and animal health, environmental protection, and the harmonious coexistence of GM and non-GM crops.

Scientists, meanwhile, are developing tools for GMO detection, containment, and risk assessment. They are also producing a whole new generation of transgenic plants able to avoid the potential pitfalls of the first-generation GMOs (see the project presentations for examples). These combined efforts and a constructive dialogue should make it possible to work out safe and accepted conditions for exploiting GM technology in Europe.



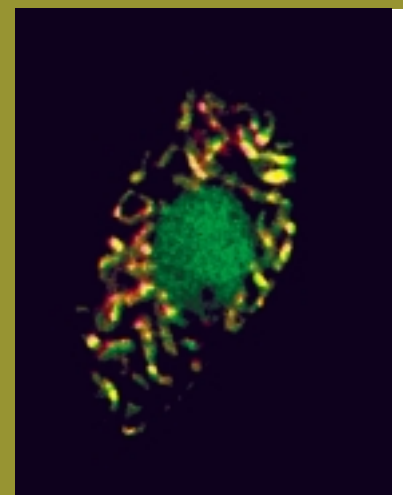
Research priorities: New topics identified by workshop participants for FP6 Thematic Priority 5 'Food Safety and Quality'

- **A Solanaceae Integrated Project** with tomato as its 'flagship' species but extending the research to eggplant, potato, etc. Such a project could emphasise fruit quality, and would stand to gain from EU support to relevant international genome sequencing projects.
- **Biological control of plant diseases/pathogens** as a means of reducing pesticide use and hence pesticide residues in food.
- **Interactions between plants and other organisms** – in particular, how these interactions affect expression of key plant genes.
- **Reducing fungal toxins in food**
- **Chemical residues in food:** where do they come from, and how and when do farmers decide to spray or not to spray? Research could provide a basis for cost-benefit estimates and contribute to prioritising the replacement of certain chemicals in agriculture.
- **Cell systems biology, the study of metabolic networks, and the analysis of cell-cell interactions** – knowledge in these fields could support a wide range of studies.
- **Exploiting rice genome sequence information for crop quality** – for instance, to reduce anti-nutritionals such as phytate.
- **Food plants with novel functionalities:** such research could involve a wide range of partners – plant scientists, nutritionists, food scientists, flavour manufacturers...
- **Exploring how to improve plants to aid the prevention of obesity, allergies, or problems of ageing.**
- **The impact of different production systems on product quality and the environment.**
- **GMOs:** new approaches to containment, technologies to avoid mixing GM and non-GM agricultural products, crop separation and coexistence.
- **Quality assurance technologies** for conventional, organic, and GMO-based farming systems: diagnostics, tracking and tracing, identity preservation, etc.
- **Risk assessment for new technologies** used in crop improvement and food production. This would include GMOs but the scope would be much broader.
- **Water use efficiency:** perhaps more appropriate for Thematic Priority 6 (Sustainable Development and Global Change), this topic may apply to Priority 5 if it emphasises product quality as well as price/yield.

Terminology guide

The project descriptions on the following pages provide a glimpse of what plant genomics and biotechnology have to offer. Below is a short explanation of the most popular words and phrases:

- **Genomics** is a new scientific discipline that studies organisms in terms of their genomes. **Structural genomics** deals notably with **markers** ('landmark' sequences), genome maps, cloned genome fragments, sequencing, and gene discovery. **Functional genomics** aims to explain gene functions.
- **Bioinformatics** is a pillar of genomic research. It includes all the computer tools and methods needed to manage genomic data and extract meaningful information from it. For instance, the function of a sequenced gene might emerge from a database search for similar genes with known functions. In particular, a protein playing a key role in one species often has counterparts in other species, encoded by similar genes. This highlights the importance of having complete genome sequences for model organisms such as *Arabidopsis*.
- **Genetic modification** refers to various techniques for inserting, removing, or altering genes. Commonly equated with **transgenesis** (inserting one or more genes from the same or a different species into an individual organism), it is both a breeding tool and a research tool which is indispensable to discovering the roles of genes and the link between genes and traits.
- A **gene is expressed** when the protein it encodes is formed. This involves **transcription** of the gene to messenger ribonucleic acid (mRNA), exit of a processed mRNA from the cell nucleus, and **translation** of the RNA 'message' into protein. Sometimes gene expression is equated with transcription, a crucial step subject to complex regulation. Analysis of the tissue-specificity, timing, and regulation of gene expression provides clues to gene functions and contributes to understanding processes such as host-parasite interactions or a plant's response to environmental stress.
- **DNA microarrays**, used notably to study the expression of hundreds to thousands of genes at a time, exploit the fact that DNA normally exists as two 'complementary' strands held together by bonds that can be broken and re-formed. Single strands immobilised on a support are used to 'fish' for complementary strands. Successful pairing is usually signalled by a fluorescent label.
- **Marker-assisted breeding** relies on **polymorphic markers** (markers existing in several variants within a species). The idea is to select for marker variants 'genetically linked' to desirable trait-gene variants (i.e. located near the trait-gene and passed on from parents to progeny along with it).
- **Quantitative trait loci (QTL)** are marker-delimited genomic regions associated with variation in 'quantitative traits' - such as yield or plant size - showing continuous variation in a population. QTL identification relies on marker maps and genetic linkage studies.



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Resourcing diversity

Plant genomics for biodiversity

In the past, farmers developed their own plant varieties which were adapted to local needs, climate, soils, etc., notably by crossing them with wild or weedy relatives. Today, genetic diversity, essential to crop improvement, is being eroded by the widespread introduction of commercial varieties. One solution has been to store germplasm (seeds, cuttings, etc.) from local varieties and wild species in genebanks, and to give breeders access to this material. Genomics is yielding powerful technologies for characterising and exploiting this gene pool.

The project 'Analysis and exploitation of germplasm resources using transposable element molecular markers' (TEGERM) concentrates on pea, barley, and tomato. It aims to develop, validate, and apply high-throughput marker systems for estimating the genetic diversity of genebank resources, before assessing their potential to facilitate the extraction of useful traits into breeding materials.

The project rationale is as follows:

- The level of genetic diversity in current agricultural breeding programmes is low.
- To promote a more sustainable agriculture, future breeding programmes will have to focus on new traits such as the ability to grow organically with less fertiliser and the inbuilt resistance to pathogens or environmental stress.
- GM technology can supply useful traits, but its future in EU agriculture remains unclear; without it, breeders must rely on gene bank resources and marker-assisted breeding.
- The 'passport data' describing gene bank accessions seldom includes genetic information. Hence, the available gene pool is uncharacterised and underexploited.

New markers and methods

TEGERM focuses on the genomic changes produced by retrotransposons, i.e. retrovirus-like DNA sequences that insert themselves irreversibly into a genome and then spread from one site to another by a 'copy-and-paste' mechanism (at the approximate rate of one insertion every million years). The idea is to identify and exploit past insertion events.

The project has yielded many markers and several high-throughput scoring systems. The most promising of these, used successfully to score 3 000 DNA samples on a single microarray, is also applicable to 'single nucleotide polymorphisms' (SNPs – sites differing by a single nucleotide). The technology has been applied to an entire pea germplasm collection, and other analyses have provided insights into the evolution and domestication of the pea.

To assess the possibility of using the new markers to extract useful characters into breeding materials, partners have established mapping populations of pea and barley and are testing the association of tomato markers with resistance to several diseases.

Contact:

Dr Andy Flavell
University of Dundee, UK
a.j.flavell@dundee.ac.uk

Biotechnology against plant diseases

Plant pests and pathogens are responsible for the loss of up to 15% of the world's potential food-crop yield. Plant science and molecular biotechnology may help solve this problem through an improved knowledge of host-pathogen interactions, the development of new diagnostic tools, and the use of genetic modification to develop durably resistant crop-plant varieties.

Resisting the nematodes

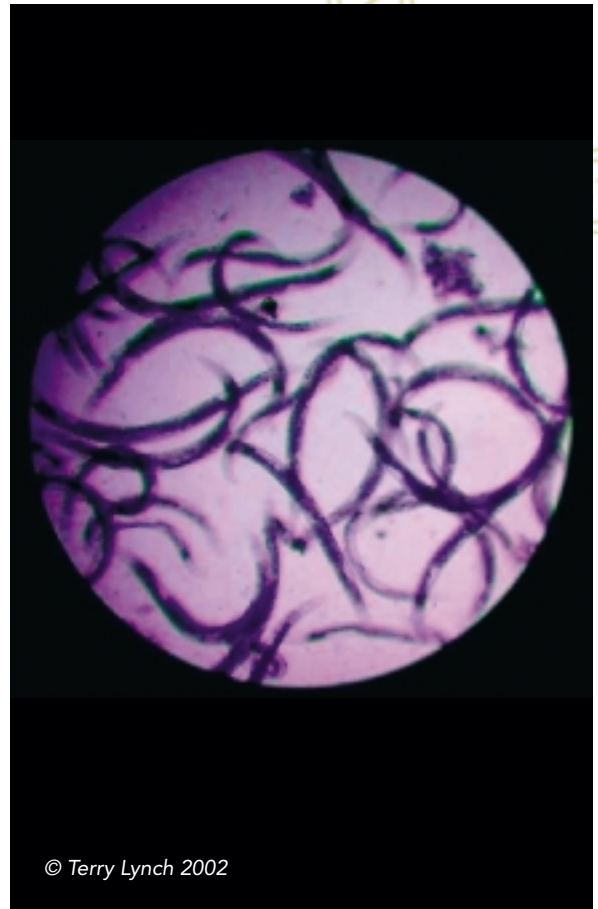
Parasitic nematodes (threadworms) affect many crops, causing severe losses. Current solutions include rotation of parasite-prone and parasite-resistant crops (but this does not work with nematodes with a wide host range), soil fumigation (banned in many EU countries because it destroys soil fauna and flora), pesticides such as acetylcholinesterase inhibitors (which do not target nematodes specifically), and the introduction of resistance genes by conventional breeding (this is time consuming, it may alter quality traits, and introduced resistance is subject to breakdown as pests evolve).

Since current methods for fighting nematodes are unsatisfactory, the project 'Making plants resistant to plant-parasitic nematodes: no access – no feeding' (NONEMA) aims to engineer broad and durable nematode resistance into crop plants. Focusing mainly on two crops of major economic importance in the EU (potato and tomato), NONEMA illustrates how basic knowledge about host-parasite interactions can lead to innovative ways to fight plant pests.

Worming their way in

Nematodes enter a plant through the root, using a combination of mechanical piercing and cell-wall softening. They then migrate through or between plant cells to a root's central region where they initiate a feeding site. Feeding-site formation enables the parasites to pump large amounts of nutrient solutions from the plant's vascular system. The feeding site of a 'cyst nematode' consists of a 'syncytium' resulting from the fusion of as many as 200 cells; a root-knot nematode's feeding site consists of several giant cells enclosed in a gall.

The NONEMA partners aim to erect multiple barriers to nematode entry and feeding-site formation. Their strategy is first to identify and then to inhibit elements that are crucial to these processes. The focus is on nematode pathogenicity factors and on



plant proteins which the parasite exploits in order to begin feeding; cell-cycle proteins, because reactivation of the cell cycle is required for formation of a functional feeding site; and cell-wall-degrading enzymes, because feeding-site formation involves the disruption and/or modification of plant cell walls.

Host-parasite interactions

Partners have identified a dozen pathogenicity factors in cyst and root-knot nematodes. This research has led them to contradict the 'dogma' that animals are ill-equipped to degrade cell walls. In nematodes, they have discovered – for the first time in any animal – the following enzymes: cellulase, pectate lyase, polygalacturonase (these proteins break up polymer chains in the cell wall), and expansin (a cell-wall-loosening enzyme). They are now assessing the likely role of these and other nematode proteins in plant invasion.



Another interesting finding is that cyst nematodes do not use their own arsenal of cell-wall-degrading enzymes to form a syncytium. Instead, they recruit plant proteins. Four such proteins, revealed in expression studies, are currently under investigation. On the other hand, work on plant cell-cycle enzymes has yielded transgenic plant lines showing reduced susceptibility to nematode infection.

Targeted disruption

Once elements essential to nematode entry or feeding have been identified, the idea is to modify plants genetically so as to counter the nematode-favouring action of such elements. One way to do this might be to introduce a gene coding for a nematode-inhibiting protein. Another promising strategy, used successfully to knock out nematode pathogenicity factors in functional studies, is RNA interference (using double-stranded RNA to block expression of target genes – see box). Results based on these approaches provide proof of concept that it is possible to interrupt plant-nematode interactions specifically.

Precise targeting is crucial both to the success of such strategies and to public acceptance of the resulting GM plants. This means that a transgene-encoded protein or an interfering RNA should be produced only at the site where the plant-nematode interaction occurs and only in response to nematode attack. This is why another project task is to identify tissue-specific, nematode-responsive promoters (transcription-driving DNA sequences subject to regulation), for use in targeting the nematode-countering action. This work is in progress.

What is RNA interference?

Interfering RNA is double-stranded RNA (dsRNA) with a nucleotide sequence matching a stretch of mRNA. The dsRNA triggers the destruction of its matching mRNA by associating with RNA-cleaving enzymes and targeting their action to it. This prevents translation of the target mRNA into protein. It is possible to deliver interfering RNA directly into an organism (for transient interference) or to introduce an appropriate DNA construct that will ensure long-term synthesis of the desired dsRNA.



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Contact:

Dr Hans Helder
Wageningen University, the Netherlands
Hans.Helder@wur.nl

Potato chips spot pathogens



The estimated number of plant pests and pathogens in the world currently exceeds 60 000. Testing for all of these organisms would appear unrealistic, but with microarray technology it should be possible to produce a diagnostic chip for the simultaneous diagnosis of the 256 plant pests and pathogens listed in the European Plant Health Directive (formerly 77/93/EEC, now replaced by Directive 2000/29/EEC). This is the rationale behind the project 'Feasibility of an EU Plant Health Directive (77/93/EEC) diagnostic chip' (DIAG CHIP).

Model methodology

To demonstrate the feasibility of this approach, the DIAG CHIP partners want to develop an array of all EU quarantine potato pathogens: 12 viruses, two bacteria, one fungus, six nematodes, one viroid (small infectious units consisting of naked non-coding circular RNA), and one phytoplasma (bacteria-like plant pathogens).

The idea is to immobilise pathogen- or pest-specific DNA or RNA probes on a 'chip' (microscope slide), to expose the slide to sample DNA labelled with a fluorescent dye to allow hybridisation (i.e. binding of DNA molecules present in the samples to complementary probes), and to scan the chip with a laser to detect fluorescence. To increase the sensitivity of the method, exploitation of the Polymerase Chain Reaction (PCR) – by which a DNA or RNA sequence present in very few copies can be amplified for better detection – is envisaged.

Ringing the changes

The work involves identifying target sequences, generating chips, preparing samples, carrying out hybridisations, and analysing the results. Bioinformatics is an essential tool here. As this work progresses, there will be cross-fertilisation between this project and other studies. In particular, collaboration has already begun with a group focusing on grapevine viruses. In addition, DIAG CHIP stands to benefit from systematic genome



sequencing. For instance, the volume of sequences available in databases for whitefly (whiteflies are sucking insects that feed on plant sap) is currently doubling every 14 months.

The final stage of the DIAG CHIP project will be development of a 'ring test' where, following a training course to facilitate technology transfer, the technology developed will be evaluated by potential end-users (five central diagnostic laboratories are associated with the project).

Contact:

Dr Ian Barker
UK Department for Environment,
Food, and Rural Affairs
i.barker@csl.gov.uk

Antibodies target plant viruses



Grown for both fruit and wine, grapes are an economically important crop in the EU. Assuming consumer acceptance of GM foods, genetic engineering has the potential to generate pathogen-resistant grapevine varieties with unaltered quality traits. The project 'Engineering durable resistance in grapevine: a novel strategy for integrated disease management to overcome environmental impact of pesticides' (RESISTANCE IN GRAPEVINE) is a cutting-edge illustration of such an approach.

The RESISTANCE IN GRAPEVINE partners aim to engineer transgenic rootstock and grapevine varieties showing durable resistance against viruses. The idea is to make plants produce transgene-encoded antibody fragments that specifically bind to key viral proteins, thereby hindering their action. Past work on other plants has demonstrated that such an antibody-based resistance approach can be successful.

Potential targets of antibody action include proteins essential to virus entry into plant cells, virus disassembly and replication of viral DNA inside the cell, or the movement of this DNA within the plant.

The strategy is to immunise chickens or mice with a target protein so as to derive from these animals a 'library' of genes coding for the antigen-recognising portions of antibodies, to select genes coding for antibody fragments that bind with high affinity to the target protein, and to engineer selected genes into plants. For both detection of target-binding antibody fragments and immediate isolation and cloning of the corresponding genes, partners are using a technique called 'phage display' (see box).

News on the grapevine

RESISTANCE IN GRAPEVINE has already yielded a wide range of tools: DNAs coding for viral proteins, optimised procedures for purifying plant-virus particles, vectors for expressing viral genes in bacteria, monoclonal antibodies binding to virus particles, antibody fragments binding to a viral coat protein, a vector for expressing foreign genes in plants, and optimised protocols for generating plant-embryo-forming material. The first transgenic grapevines should be available for analysis in early 2004.

Contact:

Dr Stefan Schillberg
RWTH Aachen, Germany
schillberg@molbiotech.rwth-aachen.de

Antibody selection by phage display

Phages are viruses that infect bacteria. They comprise a DNA enclosed in a protein coat. Phage display involves constructing a 'library' of phages bearing antibody fragments fused to surface proteins. An immobilised antigen is used to 'fish' for phages bearing antibodies capable of binding to it. The antibody-encoding DNA can then be isolated from the phage.

Fungus-resistant GM rice

Rice is grown in ten European countries, including five of the current EU Member States: Italy, France, Spain, Greece, and Portugal. Among the rice pathogens listed, fungi account for more major diseases than any other group – 36, in fact. The fungi responsible for rice blast and stem rot are the most widespread and damaging pathogens affecting rice crops in Europe. To reduce the release of fungicides into the environment and improve product safety, it is important to develop fungus-resistant varieties. In cases where resistance has been introduced by conventional breeding methods, it has broken down within a few seasons. Consequently, scientists are keen to exploit transgenesis as a means of engineering into rice durable resistance against fungi. This is the aim of the project 'European rice: transgenes for crop protection against fungal diseases' (EURICE).

Mould, moth and maize

Various organisms produce proteins with antifungal properties. The EURICE partners are focusing on genes coding for three such proteins: an antifungal protein (AFP) from the mould *Aspergillus giganteus*, cecropin A from the moth *Cecropia*, and a maize protein called b-32. The idea is to engineer rice plants to produce a defence protein, and then to challenge the resulting transgenic plants with fungal pathogens and monitor how they resist them. Refinements of this approach include gene pyramiding (combining two defence genes), the use of fungus-inducible promoters to drive transgene expression, and targeting the defence gene to the plant's chloroplasts (the organelles responsible for photosynthesis) so as to avoid transgene flow to non-GM cultivated and weedy rice through cross-pollination.

Promising results

EURICE has yielded various transgene-expressing rice plants. Among these, plants expressing an altered *Afp* gene appear to be the most promising, showing significant resistance to disease when challenged in an experimental situation with a pathogenic fungus. Fungus-inducible promoters have been found, and transgene targeting to the



chloroplast has been achieved. Further evaluation of GM lines (obtained with or without chloroplast targeting) and gene pyramiding strategies are in progress, and partners are now conducting detailed studies of interactions between GM rice plants and fungi.

Because the possibility of gene flow between GM and non-GM plants is a major issue, the EURICE partners have studied spontaneous gene flow from transgenic to weedy rice, and have established a reliable protocol for testing transgenic rice plants in the field without gene flow occurring. Field trials have been conducted in Spain and Italy, and the most promising GM lines will be evaluated further.

Contact:

Dr Elisabetta Lupotto
Istituto Sperimentale per la Cerealcoltura, Italy
lupotto@iscbg.it

Changing plant architecture and physiology

Scientists' ability to isolate, clone, knock out, insert, modify, and transfer genes has provided countless new insights into plant development and physiology at the molecular level. This in turn creates unprecedented opportunities for breeders and growers alike, broadening their scope for action to new traits and to plants with long life cycles, such as trees. GM technology carries with it a new responsibility – to contain GMOs so as to avoid adverse effects on the environment and on non-GM farming systems. However, this same technology may itself offer solutions to the problem of containment.



A good time for flowers

The project 'Control of flowering time for sustainable and competitive agriculture and forestry' (CONFLOW) aims to develop an array of genetic tools to control the time of flowering in forage grasses, rice, and both forest and fruit trees. This justification for such research is based on the following considerations.

Altering life cycles

A plant's flowering time can be very important in agriculture. For instance, Italy is Europe's biggest rice producer. To allow for the timely harvest of grains, Italian rice-growers have to plant their rice in early spring, at a time when there is still a risk that cold weather will kill the young plants. In such a climate it would be useful to shorten the rice's life cycle by reducing the interval between planting and flowering, so that the rice can be planted later in the season. In rice-growing developing countries, shortening the plant's life cycle might be even more important, if it allows an extra harvest – which could be a step towards reducing hunger in some regions of the world.

This example illustrates the importance of climate in determining both crop yield and where a crop can be grown. By adjusting the flowering time in some crops, it should be possible to extend their planting range. Such control could become vital in a future marked by major climate changes and fluctuations. Some plants have such a long life cycle that they are not amenable to improvement through selective breeding. This is the case for many trees which may remain in a juvenile (non-flowering) state for up to 30 years. It is therefore no surprise that conventional breeding has had little impact on fruit and forest trees. If the juvenility period were to be shortened, this could pave the way to enhancing the productivity and competitiveness of EU forestry and fruit production through the introduction of desirable traits by marker-assisted selection.

In other cases, it might be useful to inhibit flowering altogether. For example, this could be a way of improving the quality of forage grasses, because flower-bearing grass stems contain large quantities of indigestible compounds. By ensuring the availability of high-quality grass throughout the season, non-flowering forage grasses should allow more simple and flexible grazing and rotation systems. And, if at some point it might prove valuable to produce seeds from such grasses, it would be useful to have a means of stopping and triggering the flowering process at will.

Containing transgenes

The project descriptions presented in this brochure are full of examples of potential benefits of GM plants in agriculture. This research tends to target food crops, but there are other opportunities, such as the use of genetically engineered plants to produce vaccines and pharmaceuticals. GM technology could also contribute to enhancing the competitiveness of EU forestry. Nevertheless, the use of GMOs does raise environmental issues: (1) the risk that a transgenic plant might become invasive and disrupt non-cultivated plant communities; and (2) the risk of transgene flow to non-GM cultures. In particular, the latter could threaten the development of organic farming which is another activity considered important for EU agriculture. Inhibition of flowering in GM cultures – or its timing to avoid cross-pollination with surrounding plants – might provide an effective means of GMO containment.

Achievements

CONFLOW pursues a triple goal: fine-tuning of flowering time, accelerated improvement of woody species, and biological containment. This translates into the following specific objectives: control of flowering and vernalisation (flowering after a cold period) in ryegrass; early and late flowering in rice; late- or non-flowering forest trees; extremely early flowering in forest and fruit trees.

In the model plant *Arabidopsis*, partners have managed to switch off flowering by means of a (permanently expressed) transgene coding for a floral inhibitor, and then to switch flowering back on by triggering expression of an inducible transgene coding for an antagonist of the inhibitor. The approach is being extended to ryegrass, and non-flowering ryegrass plants are now being tested in gene-flow and containment trials. Research has also yielded early- and late-flowering birch trees and early-flowering citrus trees. Microarrays have been developed to identify vernalisation-responsive genes in ryegrass, and encouraging results are emerging from studies aiming to determine how over-expression of candidate rice genes affects flowering in rice.

Contact:

Dr Claus Andersen
DLF-Trifolium A/S, Denmark
claus.h.Andersen@risoe.dk

Optimising greenhouse tomatoes



Hothouse tomatoes are an important agricultural product for several European countries. Although the sector uses high-yield tomato varieties well adapted to greenhouse conditions, several problems remain to be solved. The project 'Architecture Engineering in the Tomato' (OPTOMIZE) is pursuing the following goals:

- **to eliminate side shoots:** side shoots reduce yield from the main stem and have to be removed manually. This means increased labour costs and a greater risk of plant disease due to penetration of pathogens through the 'wounds' created by side-shoot removal;
- **to optimise leaf shape and the leaf-to-inflorance ratio:** leaves are essential for photosynthesis, but the fruit yield depends on the number of flowers. In addition, leaves can obstruct light penetration, while the removal of old and dying leaves also poses the problem of labour costs and risk of disease;
- **to synchronise flowering** for the development of more uniform fruit, size, and ripening;
- **to improve fruit quality** (taste and health benefits) by increasing synthesis of the anti-cancer compound lycopene, of antioxidants such as beta-carotene, vitamins, and flavonoids, and of flavour-promoting substances and sugars.

New varieties

The OPTOMIZE strategy relies on both GM technology and on studying how mutations (sequence changes) in key genes affect tomato plants. Project results should be applicable either to traditional breeding or to the creation of GM tomato varieties with novel benefits for growers, consumers, and the agro-biotech industry. To encourage acceptance of such varieties, the partners have chosen not to introduce foreign genes into tomato plants, but instead to focus solely on normal or mutated tomato genes.



One line of the research concerns a gene called the 'lateral suppressor' (LS) gene. When this gene is mutated, side-shoot formation is inhibited. Unfortunately, the mutation also impairs flower development. In OPTOMIZE, partners aim to dissociate the mutation's wanted and unwanted effects. One strategy is to target expression of a normal LS gene specifically to the flowers of a mutant plant, while another is to inhibit LS gene expression in normal plants, but only in the region where side shoots form.

To improve tomato quality, teams are focusing on both the fruit-ripening process and the tomato plant's response to light. This work has yielded some very interesting mutants which show clearly that fruit quality can be improved by this approach. Particularly noteworthy is a double mutant producing extremely high levels of anthocyanins (pigments that are also powerful health-promoting antioxidants). Such a tomato has great potential as a 'functional food'. Work on various other project goals is also progressing.

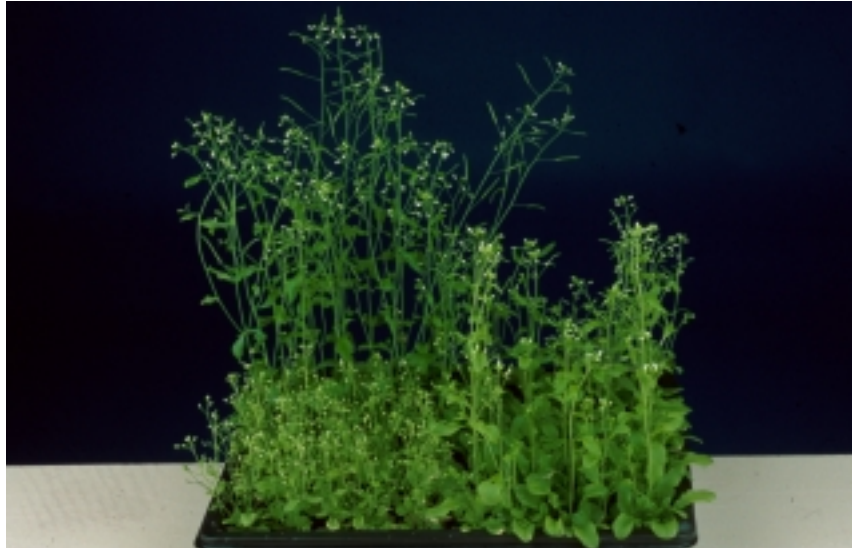
Contact:

Dr Chris Bowler
Stazione Zoologica Anton Dohrn, Italy
chris@szn.it

Growth and sustainability



According to FAO (Food and Agriculture Organisation) figures, some 800 million people worldwide were undernourished between 1998 and 2000. What is more, the world population is expected to grow from about 6 billion today to nearly 9 billion in the 2060s. Consequently, substantial increases in crop yields will be required to feed so many people. However, intensive, high-input agriculture is not sustainable, mainly because it pollutes the environment with agrochemicals and contributes to the depletion of water resources. This highlights the need to develop plant cultivars that use water and nutrients more efficiently and give higher yields, notably under less-than-optimal conditions. Current knowledge of how genetic and environmental factors combine to influence plant growth and yield is inadequate. To enhance such knowledge and point the way towards its application in agriculture is the main objective of the project 'Growth, Vigour, Environment' (GVE).



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Model behaviour

GVE exploits the *Arabidopsis thaliana* model, the advantages of which include the availability of its complete genome sequence, its kinship with the crop plant rapeseed (the two plants show close sequence similarity over 85% of their genomes), the considerable natural variability of its growth characteristics, and its long-standing use in physiological, genetic, and transgenesis studies. The idea is to 'fish' in *Arabidopsis* for genes that control plant vigour, to test their effects in rapeseed and rice, and to look for similar genes in these crop species. Of particular interest are 'master genes' that 'sit' at pathway intersections and respond to environmental factors. The work should provide a basis for marker-assisted breeding and/or for the development of high-performance GM varieties. The project partners have put together a unique col-

lection of naturally occurring and genetically modified *Arabidopsis* lines, showing widely varying growth features. They have defined standardised growth-limiting culture conditions for analysing plant performance. They have also worked out high-throughput and in-depth methods for analysing growth of *Arabidopsis* and rice in terms of root growth, leaf area, seed number, size and weight, cell size and cell division, and so on.

The GVE strategy for identifying growth- and yield-controlling genes is multiple and integrated. In particular, it includes QTL mapping to identify markers (and eventually specific gene variants) associated with specific features, expression profiling under various conditions, and functional studies focusing on candidate genes. The project has generated a wealth of basic knowledge and useful tools, and several genes shown to influence yield in *Arabidopsis* will soon be tested in rapeseed and rice.

Contact:

Dr Laszlo Bogre
University of London, UK
l.bogre@rhul.ac.uk

GMOs: soil ecology and economics

ECOGEN, the 'Soil ecological and economic evaluation of genetically modified crops' project will contribute to both regulatory and economic decision-making as regards the use of GMOs in EU agriculture. Significantly, it is generating knowledge that will be useful in assessing the environmental risk of GM crops according to Directive 2001/18/EC.

The scientific focus of ECOGEN is the soil ecosystem, an area often ignored in environmental impact studies. Because conventional agricultural practices (e.g. pesticide use) also affect soil ecology, the project partners will compare the effects of GMO-based and conventional farming systems to see whether the GMOs tested represent an environmental risk (at the level of the soil) or whether, on the contrary, they are likely to contribute to greater sustainability.

ECOGEN also has an economic focus. The idea is to build scenarios for analysing the impact of different EU policies on the net benefits of planting GM crops. Then, taking both ecological and economic factors into account, the ECOGEN partners aim to build an integrated rule-based model for assessing the sustainability of both GM and non-GM farming.

Scaling up

Focusing on transgenic and non-GM maize, the ECOGEN soil ecology teams are working at three different levels: laboratory, greenhouse, and field. Lab studies are focusing on the effects of plants and pesticides on single, agriculturally significant soil organisms (earthworms, snails, root-feeding insects, nematodes, microbial species, etc.). At the other end of the scale, conventional and GMO-based farming systems have been established at three European sites, representing different European climates (from cool temperate to dry Mediterranean). Greenhouse studies provide a link between lab tests and field trials and are concentrating on 'mesocosms', i.e. pots containing the same soils, planted with the same plants, and subjected to the

Assessing the impact of GM crops

As has been highlighted throughout this brochure, GM technology may be a key both to boosting the competitiveness of EU agriculture and to making it more sustainable. However, citizens in the Union are wary of GMOs, and have raised issues in this context which must be addressed. This is why EU policy-makers have been working hard to develop a regulatory framework that will make it possible to exploit the innovation potential of biotechnology in agriculture under conditions that are acceptable to European citizens. Under Directive 2001/18/EC, no GMO can be released into the environment without prior authorisation. Such authorisation is subject to a comprehensive health and environmental risk assessment. If an unmanageable risk is identified, authorisation should be refused; if no risk is identified, authorisation should be granted; and if a manageable risk is identified, authorisation should carry with it the obligation to implement risk-management measures. In the case where a GMO is authorised for cultivation, yet another issue arises: what measures must be taken to allow for the coexistence of GM and non-GM crops while preventing cross-contamination between them? Research within FP5's Key Action 5.1.1 is helping to build a scientific basis for making regulatory decisions on GMOs in agriculture and for resolving the coexistence issue. It is also addressing the question as to what measures are needed to make transgenic crops and GM foods acceptable to EU consumers.

same pesticide treatments as in the field, but under defined environmental conditions.

Policy and consumers

The teams targeting economic aspects are interested in the impact of different measures that might be applied to GM crops in Europe, such as a tax on GM crops to cover insurance for possible risks, minimum distances imposed with respect to fields planted with organic crops, or strategies



aiming to slow the development of insect resistance to insecticide-producing transgenic crops. Labelling requirements for GMOs are also being considered, and consumer acceptance is being modelled. The latter involves differentiating between consumers who are willing to pay a premium for non-GM crops and those who are not.

The rule-based modelling teams aim to build a decision-support tool combining ecological and economic aspects. The tool should include a model of the impact of pesticides and GM crops on non-target organisms and soil functions. Special training is being provided within the project to facilitate knowledge transfer from soil biologists, ecotoxicologists, and economists to the model builders.

Progress and prospects

Project field experiments were established in 2001-2002 at northern and southern European field locations, and an extensive sampling programme is running at these sites. So far the work has highlighted the importance of cropping sequence and soil tillage as crucial factors affecting soil ecology and quality. It has also shown that it is important

to take the maize variety into account when assessing soil effects. In single-species lab tests, Bt maize (insecticide-producing transgenic maize) has shown no effect on non-target soil organisms.

ECOGEN is expected to yield abundant, in-depth knowledge on the soil ecosystem. By focusing on the effects of both GM and non-GM cropping systems, it should provide a sound basis for estimating both the costs and the benefits of introducing GM plants into European agriculture.

Contact:

Dr Paul Henning Krogh
National Environmental Research Institute, Denmark
phk@dmu.dk

GM strawberries: fruitful developments



The idea behind the project 'Sustainable production of transgenic strawberry plants: molecular aspects, ethical and sociological consequences' (TSP-EEES) is to focus on an agricultural problem that is not readily solved by conventional breeding and to develop a risk-minimising transgenic solution. Parallel aims are to examine the ethical acceptability of releasing such a product and to see how industry, consumers, and society at large are likely to respond to it.



Fighting fruit rot

The scientific focus of TSP-EEES is fruit rot (grey mould) in strawberries. This is a major problem in strawberry production which can result in losses of up to 30% of a crop. Current fungicides are potentially toxic and are unable to totally control the disease. Both producers and consumers stand to gain from replacing traditional varieties of the fruit with a fungus-resistant cultivar, but conventional strawberry breeding is difficult so a GM approach may prove to be the best option.

The partners are concentrating on a natural strawberry defence protein which inhibits an enzyme that the fruit-rot fungus uses to invade strawberry cells. Partners have shown that expression of the inhibitor gene is normally low in ripening fruit and much higher in ripe red fruit. Whatever the fruit stage, expression increases transiently in response to fungal attack. Consequently, the idea is to engineer plants to produce a constant high level of defence protein at all fruiting stages.

The first transgenic plants resulting from this work are now being tested in the greenhouse for resistance to the fruit-rot fungus. The project partners' intention to minimise any health risk that might be associated with GM strawberries is being expressed in their focus on a normal strawberry gene and

efforts to refine the approach with 'clean vector technology' – which eliminates non-strawberry selection markers while leaving the strawberry 'payload DNA' in place – and the use of strawberry regulatory sequences.

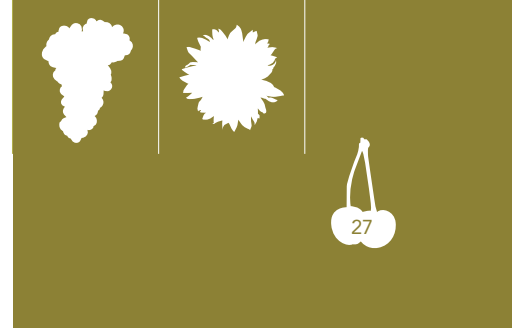
Accepting GM foods

On the basis of a list of risks and uncertainties, teams focusing on the ethics of GM strawberry production are striving to translate the precautionary principle into practical terms. In parallel, partners have conducted surveys and in-depth interviews to explore farmer and consumer attitudes towards GM strawberries. Although scepticism prevails, a shift towards greater acceptance seems possible if there are clear economic, environmental, and health benefits linked to reduced fungicide use. By taking all these different aspects into consideration, this low-risk project may provide a model for exploiting GM technology in a manner acceptable to European consumers as a whole.

Contact:

Dr Tor-Henning Iversen
Norwegian University of Science and Technology
Tor-Henning.Iversen@chembio.ntnu.no

List of FP5 Key Action 5.1.1 'Sustainable Agriculture' projects related to plant genomics and biotechnology



- [QLK5-CT-1999-01462](http://www.eu-dream.nl) Durable resistance management of the soil-borne quarantine nematode pests *Meloidogyne chitwoodi* and *M. fallax* (DREAM)
<http://www.eu-dream.nl>
- [QLK5-CT-1999-01471](http://www.plant.wageningen-ur.nl/projects/discover/) Development of diagnostic tools and host plant resistance to control the rapid spread of lettuce big vein and ring necrosis disease in leafy vegetables (DISCOVER)
<http://www.plant.wageningen-ur.nl/projects/discover/>
- [QLK5-CT-1999-01484](http://www.cerealicoltura.it/Eurice/Eurice.htm) European rice: transgenes for crop protection against fungal diseases (EURICE)
<http://www.cerealicoltura.it/Eurice/Eurice.htm>
- [QLK5-CT-1999-01501](http://nonema.uni-kiel.de/) Making plants resistant to plant parasitic nematodes: No Access - No Feeding (NONEMA)
<http://nonema.uni-kiel.de/>
- [QLK5-CT-2000-00357](http://www.szn.it/plants/EU-fundedprogrammes/optomize) Architecture engineering in the tomato (OPTIMIZE)
<http://www.szn.it/plants/EU-fundedprogrammes/optomize>
- [QLK5-CT-2000-00722](http://www.gene-mine.org/) Improved use of germplasm collections with the aid of novel methodologies for integration, analysis and presentation of genetic data sets (GENE-MINE)
<http://www.gene-mine.org/>
- [QLK5-CT-2000-00764](http://www.iger.bbsrc.ac.uk/igerweb/SAGES/Welcome.html) Sustainable grasslands withstanding environmental stresses (SAGES)
<http://www.iger.bbsrc.ac.uk/igerweb/SAGES/Welcome.html>
- [QLK5-CT-2000-00902](http://www.hybtech.org) Development of an environment-friendly F1 hybrid breeding technology (HybTech)
<http://www.hybtech.org>
- [QLK5-CT-2000-01479](http://www.eu-strawberry.com) Sustainable production of transgenic strawberry plants; ethical consequences and potential effect on producers, environment and consumers (TSP-EEES)
<http://www.eu-strawberry.com>
- [QLK5-CT-2000-01502](http://www.biocenter.helsinki.fi/bi/tegerm/tegerm.htm) Analysis and exploitation of germplasm resources using transposable element molecular markers (TEGERM)
<http://www.biocenter.helsinki.fi/bi/tegerm/tegerm.htm>
- [QLK5-CT-2001-00934](http://www.niab.com) Genetic diversity in agriculture: temporal flux, sustainable productivity and food security (GEDIFLUX)
<http://www.niab.com>
- [QLK5-CT-2001-01183](http://www.molbiotech.rwth-aachen.de/grapevine.htm) Engineering durable pathogen resistance in grapevine: a novel strategy for integrated disease management to overcome environmental impacts of pesticides (RESISTANCE IN GRAPEVINE)
<http://www.molbiotech.rwth-aachen.de/grapevine.htm>
- [QLK5-CT-2001-01262](http://www.risoe.dk/) Efficient utilisation of forage maize by dairy cattle: plant parameters, genetic determinism, impact on milk production, animal behaviour and environment (SILEGENEQUA)
<http://www.risoe.dk/>
- [QLK5-CT-2001-01412](http://www2.rhbnc.ac.uk/~ujba110/gve/gve.htm) Control of flowering time for sustainable and competitive agriculture and forestry (CONFLOW)
<http://www2.rhbnc.ac.uk/~ujba110/gve/gve.htm>
- [QLK5-CT-2001-01461](http://www.iacr.ac.uk/cpi/sustain/sustain.htm) Developing wheat with enhanced nitrogen use efficiency towards a sustainable system of production (SUSTAIN)
<http://www.iacr.ac.uk/cpi/sustain/sustain.htm>
- [QLK5-CT-2001-01871](http://www2.rhbnc.ac.uk/~ujba110/gve/gve.htm) Growth, vigour, environment - molecular breeding for plant growth and yield (GVE)
<http://www2.rhbnc.ac.uk/~ujba110/gve/gve.htm>
- [QLK5-CT-2001-02044](http://www.boku.ac.at/fucomyr/) Novel tools for developing Fusarium-resistant and toxin-free wheat for Europe (FUCOMYR)
<http://www.boku.ac.at/fucomyr/>

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- [QLK5-CT-2001-02270](#) Feasibility of an EU Plant Health Directive (77/93/EEC) diagnostic chip (DIAG CHIP)
<http://www.diagchip.com/>
- [QLK5-CT-2001-02445](#) Natural oxylipins and defence in ornamentals (NODO)
<http://www.cnb.uam.es/~nodo/>
- [QLK5-CT-2002-00841](#) Regulation of osmotolerance: molecular breeding for improvement of plant drought, salt and cold stress tolerance (ROST)
<http://www.tau.ac.il/~hanans/ROST/>
- [QLK5-CT-2002-00862](#) Development of ryegrass allele-specific markers for sustainable grassland improvement (GRASP)
<http://www.grasp-euv.dk>
- [QLK5-CT-2002-00914](#) Exploiting the genomes of diverse Pseudomonas biocontrol strains for sustainable agriculture, to protect the environment and to improve human health by production of healthy food (PSEUDOMICS)
<http://www.pseudomics.nl.eu.org/>
- [QLK5-CT-2002-01278](#) Genetic evaluation of European rose resources for conservation and horticultural use (GENEROSE)
<http://www.generose.org>
- [QLK5-CT-2002-01279](#) Establishing cryopreservation methods for conserving European plant germplasm collections (CRYMCEPT)
<http://www.agr.kuleuven.ac.be/dtp/tro/CRYMCEPT/>
- [QLK5-CT-2002-01492](#) High-quality disease resistant apples for a sustainable agriculture (HiDRAS)
<http://users.unimi.it/hidras>
- [QLK5-CT-2002-01813](#) StEm Canker of oilseed rape: molecular tools and mathematical modelling to deploy dUurable Resistance (SECURE)
<http://www.secure.rothamsted.ac.uk/sc.htm>
- [QLK5-CT-2002-01666](#) Soil ecological and economic evaluation of genetically modified crops (ECOGEN)
<http://www.ECOGEN.dk>
- [QLK5-CT-2002-01849](#) Developing a physical and functional map of potato: creating new sources for molecular markers to breed cultivars with multiple resistances and quality traits (APOPHYS)
<http://www.dpw.wau.nl/pv/projects/apophys>
- [QLK5-CT-2002-02307](#) Faba bean breeding for sustainable agriculture (EUFABA)
<http://www.ias.csic.es/Rubiales/>
- [QLK5-CT-2002-70866](#) Resistance breeding against the barley leaf spot complex, a new barley disease in Europe (BARRACCUA)
- [QLK5-CT-2002-70996](#) Biological suppression of severe plant viruses (POTYPROTECT)
<http://www.potyprotect.org>
- [QLK5-CT-2002-71855](#) Improved utilisation of new genetic resources in resistance breeding against soil-borne viruses in barley and wheat by the use of molecular markers (VIRRES)
<http://www.pajbjergfonden.dk/da/VIRRES2.htm>

Further information on the projects under the Framework Programmes for research is available on the web at: • http://europa.eu.int/comm/research/agriculture/index_en.html
• <http://www.cordis.lu/fp5/projects.htm>

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