Survey on Future Plant Research Activities in Europe

European Technology Platform "Plants for the Future"
Summary Report of the Survey
10 October 2006

Executive Summary

A survey of the future plans of European researchers in the field of plant science has recently been completed. The survey, carried out by the European Plant Science Organisation (EPSO) for the Technology Platform "Plants for the Future", aimed to map the aspirations of scientists onto the strategic objectives laid out in the Strategic Research Agenda (SRA) of the Technology Platform, a long term vision of the major contributions plant science can make to future knowledge-based bio-economies. The survey requested a short description of potential future research plans and partners and responses to specific questions that allowed the planned research to be categorised according to the objectives of the SRA. The scale and detail of the responses was an important demonstration of the readiness and capabilities of the plant science community in Europe to respond to future challenges and contribute to building a strong knowledge- based bioeconomy based on plants as the principal sustainable source of food, feed, materials and energy.

The responses to the web-based survey were analysed by 4 panels of eminent scientists, industrialists and farmer representatives, who classified and summarised the responses with respect to the aims of the SRA. The outcome of the survey, summarised in this document, provides a unique view of a research enterprise from the "bottom up" at a formative time for European research. The analysis of the survey will be provided to the EC and to the Technology Platform. It may help structure the work programmes of the initial stages of Framework Programme 7 and strengthen the SRA.

The scale and detail of the responses showed that European plant scientists are ready to meet the major scientific challenges laid out in the SRA. These include generating a genomics foundation for major European crops and developing crops better able to withstand a wider range of climatic conditions and pests. Scientists also proposed using plants for large-scale production of valuable pharmaceutical products as well as bio-based materials for sustainable manufacturing and energy production. The survey also identified possible gaps in future plans in which science proposals did not address major challenges. While these may reflect a lack of response to the survey, the relative paucity of projects aimed at sustainable improvement in crop yield, for example, require special measures by the Technology Platform to promote this vitally important field.

The process

Academic and industrial scientists in Europe were invited to contribute to a survey of current and possible future trans-national collaborative research activities in Europe relevant to plant science. The survey was a timely opportunity for research scientists to respond directly to the Strategic Research Agenda (SRA) of the Technology Platform "Plants for the Future" and to the initial content of the EC FP7 Food, Agriculture and Biotechnology Programme. The outputs of the survey may help the EC formulate Work Programmes for the first two calls in FP7 (2007, 2008) and help the ERA-PG national funding agencies to identify new priority areas for possible trans-national funding.

The survey was carried out for the "Plants for the Future" Strategic Research Agenda (SRA) under the auspices of EPSO between May-June 2006 via a web-based portal. Some 280 responses and research plans were submitted from 21 European nations, involving including the indicated partners a total of 42 nations, with a total budget of nearly €1.4 bn (The breakdown of these figures by challenge and research theme is in Annex p. 20). The survey content was analysed by 4 panels of internationally- recognised scientists and industrialists during July 2006. The panels synthesised a high level inclusive view of the research topics submitted and categorised the proposed activities according to the "Plants for the Future" SRA.

The four societal challenges to which the plant research sector can contribute are articulated in the SRA Vision and Research Agenda papers as: Healthy, safe and sufficient food and feed; Sustainable agriculture, forestry and landscape; Green products; and finally, Competitiveness, consumer choice and governance.

The main conclusions of the survey

Despite the short time of one month during which the survey was conducted the research community responded with a wide range of topics that were generally directly relevant to the SRA. Most proposals were received from academia and fewer from industry, perhaps reflecting an effect of the survey period.

The responses to the survey revealed that in nearly all areas of the survey most returns were detailed and comprehensive, reflecting a mature state of preparation and a readiness to respond to the Challenges of the SRA. Several proposals spanned large research themes, for example plant biochemistry and medicine, and between mathematics and plant growth. Responses to Challenge 2, “Sustainable Agriculture, Forestry and Landscape”, and Challenge 4, “Competitiveness, Consumer Choice and Good Governance” (covering the field of basic and enabling research), were numerous (108 and 97 for challenges 2 and 4 respectively), detailed and revealed many new areas of integrated research relevant to these Challenges. In the case of Challenge 1, “Healthy, Safe and Sufficient Food”, the survey did not elicit such a large number of informative responses (32), although there were sufficient responses to formulate a clear view of the activities and priorities in this area. In Challenge 3, “Green Products”, 34 submissions were received and the panel felt there were insufficient informative responses for them to synthesise a high level overview. In this case the panel used their own expertise and knowledge of the sector and the SRA to establish an overview, and this feature of the survey should be taken into account. Subsequent analysis of the primary responses to Challenge 3 showed that nearly half of the responses aimed to develop plant- based systems for producing a variety of pharmaceutical products and bio-active molecules. Several other projects aimed to produce rubber and other bulk commodities from new sources to ensure sustainable and secure supplies of materials. Others aimed to develop new crops as sources of bioenergy. The responses demonstrate the capability of the relevant research community to develop ambitious projects relevant to the SRA. Funding agencies may also wish to consider the outcome of other recent surveys in this field. In some cases the research community did not produce the expected range of applications, for example in improving crop yield, developing improved animal feed or establishing or maintaining centralised databases and stock centres that are so vital for modern biology. These gaps are identified in the detailed report of each Challenge, indicated in italics.

The survey identified a wide range of research topics with both high socio-economic relevance and intellectual merit. By categorising these according to the SRA priorities, the survey populated the SRA with relevant, up-to-date research themes conceived by networks of scientists working in those fields. Therefore the SRA has been enlivened and transformed into a practical guide to future plant research. Furthermore, opportunities for links between projects are evident that will build new foundations for plant research. Examples of some of the proposed projects are summarised below that show the exciting potential, socio-economic relevance, competitiveness and feasibility of current European plant research.

The objective of developing healthy, safe and sufficient food was exemplified by exciting multidisciplinary work linking plant research and biomedicine. One large network aims to link research on improving levels of health- promoting plant products in crops to their clinical use in ameliorating age-related conditions. In the field of sustainable agriculture the mechanisms underlying the increased yield and vigour of hybrid crops will be studied and linked to projects in improving crop plants. Plants have significant potential for the production of a wide variety of materials in an environmentally sustainable way. Several projects were designed to produce, in an economically viable way, a wide variety of pharmaceutical and small bio-active molecules. Others aimed to develop plants for material and energy production. Projects in the area of basic research aimed to establish underpinning genomics resources in crops to support a wide range of strategic objectives. Many other projects planned to take a multidisciplinary and integrated approach to understand complex processes such as growth and environmental interactions at the molecular, cellular and whole plant level.

Relevance to the provisional Themes of FP7

The following research themes identified in the survey are directly relevant to the provisional Themes of FP7.

Theme 1. Health

III. Optimising delivery of health care to European citizens.

Diet is increasingly recognised as major factor that is required for the maintenance of optimal health in all age groups. Plants in the diet provide many compounds that promote health and combat disease. Projects that aim to alter the types and levels of health- promoting factors in plants and establish their benefits through appropriate trials, and reducing anti-nutritional, toxic and allergenic components of plants used for food, fit well within this Theme.

Theme 2. Food, Agriculture and Biotechnology

I. Sustainable production and management of resources

Projects that aim to ensure continued productivity from European crops, and to find novel uses for these within a framework of sustainable production, fit well within this Theme. The development and application of genomic resources for major European crops underpins all research in this Theme. Projects aimed at understanding and adjusting plant responses to the environment, including combating pests and

diseases, are required to ensure food security. Developing new feed crops for farm animals that reduce dependence on imports while enhancing palatability and performance are important goals. Defining the many mechanisms contributing to the final yield of crop plants, including strategies to use hybrid vigour and polyploidy and breeding new crops with improved yield with reduced inputs, is key for sustainable food production. Projects that aim to develop new crops within a framework of protecting and enhancing biodiversity in the farmed landscape are also relevant to this Theme.

II. Fork-to-farm: food, health and wellbeing
Ensuring the supply of attractive, nutritious and safe food that respects and enhances the cultural and geographic diversity of European food is a major goal. This includes multidisciplinary research with that in Theme 1, Health, which aims to understand the functions of plant compounds in promoting health, reducing allergens and toxins, and promoting a healthy life-long diet based on improved knowledge of crop plants. Research that underpins knowledge of plant growth, development, environmental interactions and metabolism is essential for the systematic improvement of the nutritional content of crop plants.

III. Life sciences and biotechnology for sustainable non-food products and processes
Because plants use the energy of sunlight to produce a myriad of non-food compounds of primary importance to humans, they can provide important solutions to the sustainable manufacture of materials, bio-active compounds and energy. Projects that aimed to develop new crops, cell cultures and production methods for pharmaceuticals, nutraceuticals, bio-active compounds, novel materials and biomass for bioenergy were highly relevant to this theme. The integration of novel plant-based production systems with sustainable production methods was also central to ensuring their compatibility with high environmental standards.

Theme 4. Energy
The use of plants as environmentally sustainable primary producers of biomass for conversion to biofuels needs to be integrated with conversion technologies, based on microbiological fermentation, such that plant biomass composition is closely optimised with conversion technologies. Integrated projects that aim to understand the composition of plant biomass, especially lignocellulosic cell wall material, and match this to optimised processing by microbial fermentation and catalysis fit well in this theme.

Theme 5. Environment
Plant research projects in other Themes cross-cut into this Theme, as the generation of food and energy has a large impact on the appearance and other functions of the agricultural and forestry environment. In particular assessments of the impact of climate change on the productivity and biodiversity of the European landscape are urgently required. Projects that aim to develop plants resistant to pathogens and/or more efficient for using nutrients or water fit well with this theme. Projects that aim to understand impacts and improve the landscape through an integrated strategy, through soil remediation, the growth of alternative crops to support biodiversity, also fit well within this objective.

Next steps
This report will be disseminated to European and national research councils and research agencies as a unique “bottom up” survey of the current preparedness of European plant scientists to contribute to strategic research objectives. The gaps between strategic objectives and research preparedness will be addressed in a series of specific workshops, for example on crop yield and green products, to forge the necessary links between scientists and applications. In parallel, the Technology Platform will develop a mechanism to encourage discussions between European and National research that promote the implementation of the Strategic Research Agenda.

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Meeting of the Coordinators:
26.7.06

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For more information on the Technology Platform “Plants for the Future”, please consult the web site www.epsoweb.org/Catalog/TP/index.htm or contact Manuela Deckers at PlantTP@psb.ugent.be.

Challenge 1 “Healthy, safe and sufficient food and feed”

Summary

The production of healthy, safe, nutritious food and feed by energy efficient and ecologically aware agriculture and downstream processing is dependent on complementarity between two industrial sectors that have traditionally been largely independent, the seed industry and the food industry. The seed industry has focused largely on the improvement of commodity crops such as cereals and some vegetables, whereas the food industry requires additional specialty crops such as durum wheat, fruits, and nuts. There is a growing interest of consumers and of food manufacturers to focus on quality products that are healthier and that have improved sensorial characteristics. Furthermore, it is desirable to produce raw materials that are better adapted to the production of particular foodstuffs, and it is now possible to envisage the development of specific plant genotypes that have optimal characteristics to fit the needs of each application.

The “Plants for the Future” survey of the research community revealed a clear readiness to address these issues. Advances in the understanding of plant biology based largely on research performed in Arabidopsis, and the demonstration of largely untapped genetic resources in wild germplasms provides unprecedented opportunities to improve contemporary agricultural practises and to develop plant varieties better adapted to today’s needs. In particular it is now possible to exploit molecular breeding technologies to improve some of the specialty crops in addition to the commodity crops, albeit not to the same resolution. Furthermore, the growing characterization of the metabolic profiles of different materials destined for human and animal consumption is permitting a better understanding of their roles in health, nutrition, and quality. In addition, the improved appreciation that the environment is likely to influence such parameters at genic, genomic, and epigenetic levels now makes the study of such phenomena tractable.

Following analysis of the EPSO survey, it is proposed that food and feed research should be developed by improving safety, by exploiting the genetic diversity in wild genotypes, by studying the effects of environment on quality and nutrition, and by supporting the improvement of specialty crops. In addition, the panel recommends that priority should also be given to improving storability and processing characters, even though the survey was mainly focused on nutritional and nutraceutical aspects.

Generalized research topics

The submissions to the ‘Food and Feed’ challenge were grouped into the following themes:
- Food health and safety
- Nutritional quality
- Nutraceuticals and food products for specialized consumers
- Feed safety and nutritional quality.

1.1. Food health and safety

Some proposals to this topic targeted the problem of mycotoxin contamination of cereal grains, and of heavy metal contamination of products derived from agriculture.

Mycotoxins are currently not a major issue for the food and feed industry because enough mycotoxin-free cereals are available globally, but rather a problem for southern European countries where difficulties in meeting European regulation standards for mycotoxin contamination. Therefore projects addressing this issue (for example development of *Fusarium* resistant/tolerant plants) would address this topic.

Reducing heavy metal contamination of food products was recognized as an emerging problem in some proposals.

<u>Possible research themes identified from project submissions</u>

- Food health:

Aimed at improving compounds in plants that are beneficial for health, from linking health benefits to certain compound(s) up to enrich and optimise such compounds. Multidisciplinary approaches linking epidemiologists, nutritionalists, food scientists, plant breeders and plant genetecists.

- Food safety:

Aimed at reducing mycotoxin content, pesticide residues, heavy metals, toxic molecules such as glycoalkaloids and trans fatty acids.

1.2. Nutritional quality

Submissions focusing on improvement of the nutritional quality of raw material that did not involve extraction for the production of supplements were grouped under nutritional quality. A large diversity of proposals focusing on different species was presented, from cereals to vegetables and fruits, with a somewhat surprising emphasis on fruits. No herbs or spices were included. Several projects considered the exploitation of genetic diversity in related wild species and included the utilization of introgression lines, as has been championed in tomato. A typical proposal contained a significant metabolomics

component, aimed at describing the metabolic profiles of tested germplasms. In some cases, specific molecules were targeted, e.g., carotenoids, polyphenolics, trace metals, folate. In addition to the integration of significant breeding, molecular genetics, and high-throughput analytical chemistry, several projects included approaches to assess nutritional value and to assess the underlying molecular basis of the effects of different molecules in a range of cell- and non-cell-based bioassays. Such multidisciplinary projects were seen by the panel to fit with the aims of the work area, although very few submissions incorporated a parallel sensory analysis. On the other hand, the panel was encouraged to see that several submissions proposed to consider the role of environmental factors in modulating and perhaps regulating nutritional value.

Possible research themes identified from project submissions

- Exploitation of genetic diversity in wild genotypes:

Aimed at characterizing nutritional/sensory richness in wild germplasms and land races, and exploiting it by introgression into commercial varieties. Projects should be tailored towards improved sensorial properties and should aim at a thorough parallel characterization of genotypes and phenotypes. Proposed projects should therefore be multidisciplinary, involving breeders, molecular geneticists, biochemists, nutritionists, sensorial panels, and possibly also epidemiologists.

- Environmental impacts on quality and nutrition traits:

Aimed at understanding genic and genomic consequences of environmental factors such as light, temperature, biotic and abiotic stresses on factors influencing plant quality and nutrition.

- Specialty crops:

Aimed at characterization and genetic improvement of the nutritional/sensory and health value of minority crops such as fruits and nuts.

1.3. Nutraceuticals and food products for specialized consumers

Submissions aimed at the characterization and exploitation of partial or highly purified fractions from plant raw material for use as dietary supplements or for healthcare were defined by the panel as nutraceuticals projects. Very few projects fit this description, and *the panel expected to see more submissions for making plant products aimed at specific sectors of the population, e.g., to fight diabetes, obesity, heart disease, macular degeneration, and cancer*. This may indicate that such research is sufficiently well advanced that it has now become of more relevance to pharmaceutical and biomedical research rather than plant research. On the other hand, some projects dealing with allergenicity of plant products were submitted, although they were not considered to address adequately this increasing problem, because they propose to study species (tomato) which do not pose a major allergenicity issue, like others do (e.g., wheat).

1.4. Feed safety and nutritional quality.

Surprisingly few projects were submitted concerning improvement of animal feed. *The panel had expected more submissions addressing the nutritional quality of such products (e.g., aimed at increasing or improving protein content or animal appetite)* but this was not the case.

1.5. Cross-cutting themes

Possible research theme:

- Storability and processing:

This theme was not addressed in the submissions; nonetheless the panel recommends that priority should also be given to improving storability and processing characters.

Aimed at the development of plant-derived raw materials better adapted to end-uses such as processing, or with improved storability. Efforts should focus on use of raw materials requiring less energy and producing less waste during processing.

Comment on preparedness of the scientific community

The scientific community appears to be well prepared to address the issues that have been identified, building on knowledge and techniques from Arabidopsis and using well studied species such as cereals, the Solanaceae, and the legumes. However, work on the minority crops such as fruits and nuts is not well advanced and standards will obviously be lower. But work on such species is likely to be driven mainly by academia, and would otherwise not be done, so it is important to encourage such work.

Members of the panel

Vincent Petiard	Nestle, FR	(Panel chair)
Dick Toet	Unilever, NL	
Peter Westhoff	Dusseldorf University, DE	
Chris Bowler	Stazione Zoologica, IT & Ecole Normale Supérieure, FR	(Panel rapporteur)

Date of panel meeting

30.6.06

Challenge 2 “Sustainable agriculture, forestry and landscape”

Summary

Plant productivity and quality at less environmental impact and higher efficiency are key aspects of the challenge 2. The panel was generally impressed by the large number of contributions received addressing the biotic and abiotic stress components but disappointed by receiving only few projects addressing genetic yield improvement (photosynthesis efficiency, assimilation of nutrients efficiency, understanding of heterosis mechanism, apomixis, etc) as well as projects addressing transverse activities (molecular – physiological – agricultural). In the topic of biotic stress, virus resistance projects demonstrated a well prepared research community. The issue of insect resistance should be completed by genomic contributions. In the topic of abiotic stress the issue of drought stress merits a higher investment of the scientific community as well as the interactions between stresses and processes affecting the fitness of plants should be covered more intensively for its practical importance. Aspects of efficiency of resource need to be addressed more intensively at levels of plant production.

Generalized research topics

2.1. Improving plant productivity and quality

2.1.1 Biotic Stress

Biotic stress resistance is an important issue to achieve the goal of productivity and quality since productions and qualities can be dramatically hurt by pathogens.

Possible research themes identified from project submissions

- Virus resistance

The topic of virus resistance is well covered by a large number of interesting proposals including virus recognition mechanisms, basis of virus pathogenicity, mechanisms of resistance to viruses and basis of durable resistance. Several crops for which virus damages are economically important are the targets of specific studies to create resistant cultivars.

- Fungal resistance

Fungal pathogens are recognized as major sources of losses in cropping systems and also susceptible to generate toxins and to reduce food safety. A large set of interesting proposals including the basis of their pathogenicity, including toxin production, the analysis of plant resistance to such pathogens based on studies on model species but also crops and specially cereals. Since fungi, unlike bacteria and viruses, have large genomes it is also planned to develop genomic resources such as genomic and cDNA sequences on fungal pathogens.

- Nematode tolerance

The important field of nematode tolerance is covered by a very limited number of proposals including for instance biofumigation spreading to control nematodes. In view of the fact that soil sterilizing agents presently used are to be banished due to environmental hazards, it is clear that further proposals would be desirable to strengthen this research area.

- Bacterial pathogens

These proposals deal with economically important bacterial diseases affecting major crops. Several proposals address specific and economically important diseases and suggest control mechanisms for them.

- Insect impact

Insects induce important losses in a number of crops and insecticide-based crop protections have various negative impacts on the environment. Alternative strategies of crop protection based on recognition mechanisms between plants, insects and their parasites have been the matter of different proposals. This includes the identification of plants producing repellant molecules, some of them being volatiles. Other proposals deal with crop protection by the production of molecules with insecticidal properties, leading to an interesting set of proposals in this area.

- General plant defense mechanisms

Although this topic looks fundamental, it has expectedly incidences on crop protection strategies and deserves attention in the context of sustainability. Important issues how plants adapt and resist to a variety of pathogens and about the flexibility of adaptation are addressed. There are fortunately comprehensive proposals covering this area of research that may also be connected with similar projects on stress signaling including a number of strong proposals addressing plant volatiles. Related to the topic of plant defense is the issue of symbiosis, parasitism (Striga) and positive biotic interactions. Mycorrhization and nodulation mechanisms have to prevent non-self recognition involved in pathogen resistance to establish and interesting proposals on nodulation and micorrhization have been submitted.

2.1.2 Abiotic stress

Abiotic stress can dramatically decrease production qualities and quantities and therefore competitiveness. Some of the projects also address wider issues like “water use efficiency”

Possible research themes identified from project submissions

- Salt stress

Intensive soil irrigation often leads to salt accumulation and to yield losses. The problem is expected to increase further as an indirect consequence of global climatic changes. Two types of proposals were submitted on this issue. One approach is to study plants adapted to high salt concentrations such as halophytes and understand how it works, another is to exploit genetic diversity of crops to improve their tolerance to salts. This includes rice wheat and forages.

- Drought stress

Drought is one of the major a biotic factors affecting yield with an increasing importance with climatic changes (see also challenges 2.1.2.2 and 2.2.2). The number of proposals in this area is only covered by a small number of proposals addressing drought tolerance of cereals and adaptation of the root system to water stress. This issue merits a higher investment of the scientific community.

- Metal stress

Tolerance against toxic metals is of crucial importance for plant production on high metal sols as well as for phytoremediation processes. A small number of proposals address these questions using natural genetic diversity and more specific aspects of phytoremediation.

- Stress interactions

A project on abiotic stress signaling covers the important issue of adaptation to varieties of stresses. Proposals on specific issues such as cold tolerance have been also presented. It would make sense to have an integrated approach on the issue of stress biology AND pathogen resistance in higher plants.

2.1.3 Yield improvements

Yield improvements are important not only for food and feed but also in the context of biofuels and biorefineries. Therefore this topic gains additional importance in the future and is closely linked to aspects of efficiency. The panel identified a relative weakness in this important area.

Possible research themes identified from project submissions

- Photosynthesis

Targeted efforts to increase yields by improving the photosynthetic machinery is the topic of one proposal aiming at converting C3 plants in C4 plants. One proposal addresses the issue of optimizing photosynthesis also at the stand level.

- Allocation of assimilates

Targeted allocation of assimilates to harvested tissues/organs is an important aspect of agronomic efficiency. A comparative genomics approach of senescence processes in different species covers this issue as well as a project on assimilate partitioning and its consequences on yield. This issue requires additional scientific input especially in the aspect of biofuels, but also in the context of reallocating assimilates to innovative plant products.

- Heterosis mechanisms

An important goal concerns the elucidation of molecular mechanisms underlying heterosis. This question is approached by using a comparative genomics approach. As a specific tool one proposal is focused on apomixis, a breeding system that maintains heterozygosity. The introduction of apomixis into crops enables the fixation of hybrid F1 genotypes over successive generations.

- Other yield issues

Flowering time has strong influence on yields and needs to be optimized for each crop in specific environments. A large consortium has been created to study this issue.

2.2. Optimizing agriculture to further reduce its environmental impact

Besides basic improvements of plant properties, namely improved efficiency of nutrients, water, etc, the aspect of optimized agricultural practices to reduce environmental impact and maximize harvest or biomass is of crucial importance for sustainable agriculture for food, feed and biofuels. Especially the later aspect needs more attention of the scientific community, as only few proposals address this important issue. Also proposals to identify genes involved in better efficiency of plants for using nutrients and water are strongly recommended.

Possible research themes identified from project submissions

- Nutrient use efficiency

Nutrient uptake and use processes are key factors of sustainability not only because of the excessive release of fertilizers in the environment induces eutrophisation of water resources, but also because their availability will be compromised in the near future (ex: phosphate). The goals of a number of projects in the area are to achieve a better understanding of mineral nutrition processes by developing “omics” approaches on model species, and to improve nutrient use efficiency in different crops such as cereals and legumes. Plants tolerant to herbicides can have positive impact on environment. Even if this issue is already handled by agrochemical and seed companies, academic research could develop new strategies. Linked to the same issue, the analysis of nodulation and mycorhization processes and their

improvement is proposed. Finally optimization of rotation systems and agricultural practices is another research area of interest.

- Water use efficiency

Increasing water use efficiency, an obvious requirement of sustainability can be envisaged at different levels. Different proposals aim at improving agricultural practices and water management to reduce water consumption. More basic approaches are targeted on hydraulics of plants processes of stomatal aperture and other physiological processes involved in water management at the plant level. Finally, breeding approaches targeted to increased drought tolerance in important crops are proposed. Therefore improved water management can be envisaged from a combination of these different approaches.

- Reduction of agrochemical usage

A number of different strategies are envisaged to reduce agrochemical use. Quite traditional - an analysis of chemical leaches occurring in different agricultural practices can help to reduce contamination of water resources. Herbicide use can be reduced by developing a better management of weed tolerance and by technological improvement leading to the delivery of herbicides specifically on weeds, based on image recognition. As regards pest management by insecticides it is proposed to exploit signal recognition mechanisms operating between plants and insects to reduce the needs of insecticides. It is also planned to develop alternative, environment-friendly substitutes to the ongoing techniques of chemical destruction of nematodes in the soil. This area of research could lead to a substantial reduction of pollution by agrochemicals. Breeding strategies are planned to exploit the potential of self-protection against pests in major crops. Finally the use of epiphyte bacteria as barriers to pathogen penetration is envisaged to protect the root system of various crops.

- Other issues optimizing agricultural practices

Several proposals plan to reduce agrochemical use by exploiting biological control. Very diverse strategies are envisaged depending on the target pathogen or insect. The specificity of such approaches, the management of the vector used for the protection and its own control are important factors to evaluate the potential and possible dangers of these attractive approaches. The impact of climate change on carbon sequestration in agricultural practices is also a very important issue with long-term effects for soil productivity. A number of proposals also address the question of improved nitrogen input into agrosystems by the use of legumes.

2.3. Enhance and protect diversity

The understanding of mechanisms by which biodiversity is generated by the recurrent adaptation of plants in a changing environment is the theoretical basis required to devise proper strategies of management of genetic resources for crops and non-crop plants. In this context crop plants are an objective of an important proposal.

Possible research themes identified from project submissions

- The inventory of the biodiversity of resources available to improve crops by breeding

This inventory is the matter of a number of proposals on major crops and is essential for the proper management of those genetic resources in collections as well as in different geographic areas. This can be achieved more efficiently if these programs on European crops are also connected to the challenge program operating in developing countries. These different proposals provide an important starting point to tackle this important issue.

- Of concern also is the impact of farming practices on the biodiversity of organism in surrounding areas.

As a test case it is planned to study the functional biodiversity of insects in refuges located in the surrounding of farming areas. This field of research deserves however more investigations on other living organism (wild plant species and vertebrates for instance).

2.4. Enhancing the aesthetic value and sustainability of the landscape

The impact of farming practices on our environment has fortunately received attention of different applicants' proposals. Most of the envisaged studies are based on integrated approaches.

Possible research themes identified from project submissions

- Study the organization of the landscape at different organizational levels, and to analyze the incidence of different agricultural practices on its structure and evolution.

Various ways to improve the aesthetic value of the landscape rely on the

- Production and management of ornamental species not only in the country side but also in towns.

It is also proposed to improve specific problematic issues, such as

- The remediation of soils in areas polluted by metals or the management of lignocellulosic wastes.

- Finally a set of proposals are targeted on forestry issues that might be dealt better by the forestry platform.

2.5. Other issues

Possible research themes identified from project submissions

- Plants in the context of global climatic changes

A part from a small number of proposals approaching issues at the limit of the goals of PTP (ex: Germplasm collection of edible ectomycorrhizes), different reports are connected to the important issue of global climatic changes. This includes an assessment of the consequences of these changes on plant growth, based on modeling strategies. Also considered is the impact of climatic changes on soil microorganisms and on carbon balance in the soil.

In line to the same issue, it is planned to study the contribution of volatiles compounds produced by plants on greenhouse effects and to assess the contribution of different plants species to these processes through the development of approaches of environmental genomics. This group of proposals would be adequately strengthened by contributions on the incidence of different farming and forest management practices on greenhouse gas effects.

Comment on preparedness of the scientific community

Part of the scientific community appears to be well prepared to address some of the issues that have been identified, building on knowledge and techniques. However, some topics have either been slightly addressed, either not addressed. Further, if using model plants like Arabidopsis is helpful, panel believe that the use of crop plant (cereals, maize, brassicae, solanacae, legumes, etc.) of wide use for field and vegetable crops should be encouraged.

Members of the panel

Jean-Claude Guillon	Copa-Cogeca, FR	(Panel chair)
Michel Caboche	INRA, FR	
Uli Schurr	Phytosfere Juelich, DE	(Panel rapporteur)
Maarten Koornneef	MPIZ Cologne, DE	

Date of panel meetings

6. 7. and 11.7.06

Challenge 3 “Green products”

Summary

Environmentally friendly bio-based ‘green’ products are an opportunity targeting the needs of consumers, industry, society and government. European welfare depends, to a large extent, on the emergence of new markets and the growth of existing ones, while respecting the environment and responding to societal expectations. To this end, critical success factors are the ability of companies to innovate their product portfolio and production processes in line with unmet customer demand, and the endorsement of this by the public and government.

In the traditional commodity markets in plant-derived products, a growing number of companies are encountering difficulties in rejuvenating their product offerings. A key reason is that new means of extracting, processing or (chemically) modifying raw materials are running out. Diminishing global reserves and higher demands for fossil fuels, as well as growing public concern about future supply and the environmental impact of burning more fossil fuels are of increasing concern.

These trends are leading to a rapidly growing demand for quantum-leap innovations. It is plausible that many breakthroughs may derive from plants and plant-based raw materials with improved or new properties. With the explosion in biological know-how and enabling technologies, developing a broad range of new plant-based products that meet the future needs of consumers and industry, as well as those of society and government, appear feasible.

The underlying concept is that plants are exploited as a production system in the broadest way imaginable. This may include any plant species and range from their use as a production vehicle for proteins and chemicals for industrial and health use, to a renewable, totally redesigned resource for the health, nutrition, materials and energy industries. This would provide the world not only with better, cheaper and safer products, but also with totally new products, production methods, land uses, jobs and ways of living.

In view of these factors the panel identified the following topics as key research areas:

- Enabling research for developing plants as green factories
- Biochemicals and
- Bioenergy

Within this survey 34 research proposals to Green Products have been made. The information provided and the details given in the research proposals varied a lot. The panel then decided to use the outcome of the survey as a general measure for making sure that the recommendations of the panel for future research within FP7 correlate well with the topics proposed by the survey

Generalized research topics

3.1. Enabling research:

Apart from the tools which will be provided by performing basic research it will be necessary to develop tools/technologies/knowledge dedicated to exploiting plants as green factories, e.g.

- Optimisation of crop production platforms for non-food uses,
- Technologies for high yield of desired compounds under field conditions to increase cost competitiveness,
- Continuity of plant raw material composition / quality for batch stability,
- Discovery of novel crops for novel uses,
- Specialised production systems, such as plant cell cultures for contained high-level production of proteins, antibodies, bio-active molecules and pharmaceutical products,
- Understanding and optimisation of *in planta*- localisation, storage, and stability of metabolites,
- New technologies for complex metabolic pathway engineering,
- Design of new screening assays for novel functionalities,
- Design of new or advanced extraction, fractionation and purification methods (down stream processing),
- Special technologies for containment (safety).

3.2. Biochemicals

3.2.1. Pharmaceuticals:

- **Recombinant protein pharmaceuticals:**
  These can be vaccines, antibodies, toxins, allergens, or other therapeutic peptides / proteins. Research in this area has to focus on
  - Quality and quantity issues, production costs: there is urgent need to move from model systems to production crops / cell culture systems,
  - Good manufacturing practice regulations.
- **Secondary metabolites:**
  Secondary metabolites comprise a vast diversity of different chemical classes produced by plants for use in human and animal health, from anti-oxidants to anti-cancer compounds. Research in this area has to focus on
  - Linking defined novel and natural chemicals to functionalities,
  - Analytical methods to explore chemical diversity rapidly at low cost,
  - Understanding the complex biosynthetic pathways and flux control,
  - Mechanisms for increasing yields of defined metabolites.

3.2.2. Specialty chemicals and enzymes

- **Technical enzymes:**
  This topic comprises large scale production of recombinant proteins from different origins for use in diverse industrial sectors from biocatalysis to feed applications. Research has to focus on
  - Quality and quantity issues, production costs : there is urgent need to move from model systems to production crops / cell culture systems,
  - Selectivity and specificity of action, kinetics, stability in industrial use.
- **Specialty chemicals:**
  This topic comprises small molecules and building blocks from primary and secondary metabolism for applications such as lubricants, adhesives, paints, health and consumer care products, food and feed ingredients, plant protection agents as well as biocides and growth regulators. Research has to focus on
  - Linking defined novel and natural chemicals to functionalities,
  - Analytical methods to explore chemical diversity rapidly at low cost.
  - Understanding the complex biosynthetic pathways and flux control,
  - Mechanisms for increasing yields of defined compounds to required amounts.

3.2.3. Industrial feedstocks:

These are plant based building blocks such as C2, C4 molecules and derivatives. The major challenge is to boost yield in field grown crops to achieve economic competitiveness.

3.2.4. Polymers:

- **Oils:**
  Vegetable oils have multiple, large scale and uniquely important uses in diverse industrial sectors from transport fuels to lubricants and medicinal / health and consumer care uses. Research has to focus on
  - Increasing yield of novel oils with defined fatty acid composition,
  - Extraction and separation technologies to achieve defined ratios of fatty acids.
- **Rubber:**
  Demand of rubber is increasing rapidly with industrialisation of developing countries and security of regional supply may become an issue as well as supply of high quality / high value products. Research in this area has to focus on
  - Increasing knowledge of enzymes and processes involved in latex synthesis,
  - Domestication of novel rubber producing plants.
- **Starches:**
  Starch is a cheap commodity and can be modified chemically for multiple and large scale uses. Novel starch functionalities will have a broad application range in multiple industry sectors. Research has to focus on functionalised starch.
- **Novel polymers:**
  This topic comprises production of biopolymers with either unique functionalities or providing reservoirs *in planta* for post harvest base chemical production. One major challenge is to boost yield of the unique biopolymer in field grown crops to achieve economic competitiveness. Another challenge is to identify plant biopolymers with unique functionalities for industrial application.

3.2.5. Fibers:

- **Natural cellulose fibers:**
  Production of a functional end product from natural fibers involves harsh processes, resulting in large amounts of waste product and often decreased fiber quality. Research has to focus on
  - Increasing knowledge of structure and synthesis of natural fibers and how these can be modified to facilitate downstream processing
  - Technologies that add new characteristics to natural fibers and enable new applications or replace specific chemical treatments.
- **Novel fibers:**
  Plants are able to produce a broad variety of fibers: e.g. protein fibers from soybean. These provide a first commercial alternative to natural and synthetic fibers offering discrete advantages for environment and end-customer. Plants may also serve as a factory to produce fibers from other natural sources, such as spider silk.

3. 3. BioEnergy

There are multiple plant resources that are suitable for bioenergy production. The key challenges for using plants as an energy source are yield/hectare/time unit, water and input requirements, energy conversion, environmental impact and societal acceptance. To achieve the cost effectiveness needed, use of crops, by-products and residues as well as waste must be considered. The plant resources used will reflect geographical location for energy supply (e.g. forestry, grasses and field crops). Feedstocks include sugar, starch, lignocellulose and oil. There are particular challenges associated with each feedstock, particularly saccharification from lignocellulose input.

- **Biomass production**
  Currently three different types of plant resources are considered for biomass production: Field crops producing sugar, starch or oil feedstocks for the first generation biofuels, tree crops for bioenergy and dedicated energy crops for producing lignocellulosic feedstocks for the second generation biofuels. The challenges include:
  - Improved feedstock yield together with improved water and nutrition use efficiency
  - Improved lignocellulosic feedstocks with better cellulose over lignin ratios and lower nutrient content to increase the biomass conversion efficiency and reduce residues
  - Development of basic genetic and genomic resources for the use of breeding and biotechnology in improvement of the trees and perennial grasses
- **Biomass utilization**
  The primary challenge will be the development of efficient technologies for saccharification of lignocellulose, using both improved lignocellulosic feedstocks and improved enzymes for saccharification. The latter is part of the research of the Industrial Biotechnology platform.

Members of the panel

Ralf-Michael Schmidt	BASF, DE	(Panel chair and rapporteur)
Diana Bowles	York Univ, UK	
Kirsi-Marja Oksman-Caldentey	VTT Espoo, FI	
Marc Cornelissen	Bayer, BE	

Date of panel meeting
6.7.06

Challenge 4 “Competitiveness, consumer choice and governance”

Summary

In general most of the proposals were at a high stage of maturity, with specific activities and partnerships identified. This shows that the plant research community is poised, over a wide front, to establish a diverse range of trans- European research projects. The range of projects shows a trend towards integrative research involving a mixed use of research in model systems applied to objectives in crop plants. In general the projects aim to develop the research base and knowledge needed for sustainable food production and developing new crops for biomass and high value products. A full range of technology capabilities will be developed to accomplish these ambitious goals. Notably, the research community is clearly prepared to tackle the large and complex genomes of wheat, barley and forage grasses, using a combination of strategies clearly linked to crop improvement. For example, genomics information on crops will be generated and used to speed up plant breeding and make use of a far wider range of genetic variation. Integrated approaches that use the full powers of physiology, genetics and biochemistry in models will be applied within a framework of informatics for work in crop plants to enable more ambitious goals that were previously not considered as feasible. The planned research aims to discover the molecular mechanisms underlying a wider range of traits in crops, including environmental interactions, growth control and metabolism. Knowledge of these processes underpins the generation of new crops for the sustainable and environmentally compatible production of food, feed and fibre and biomass for energy production.

Generalized research topics

Possible research themes identified from project submissions

4.1. Creation of advanced genomic resources

Many were ambitious in scale and aimed to develop state-of-the-art genomic resources in major European crops, most notably wheat, barley, rye forage grasses, cucurbits, legumes, and fruit and forest trees. Notably, the research community is clearly prepared to tackle the large and complex genomes of wheat, barley and forage grasses, using a combination of strategies clearly linked to crop improvement. These projects provide key underpinning for future work in all areas of plant and agricultural research. Many of the projects had genome analysis embedded in a network of applications and biological discovery. The projects should anticipate lower-cost genome sequencing towards the second phase of FP7. However, there is a need to organize and support large-scale sequencing and analysis facilities to facilitate European projects involving a wide range of organisms.

The European research communities of the different strategic crops are already well organized in multinational research consortia. There may be advantages in linking consortia, for example to generate or gain access to technology and to tackle large objectives. Overall, the research proposals are well conceived to maximize the utility of the resources in achieving the aims in challenges 1 – 3.
It is strongly recommended that this research topic receives appropriate funding at the European level (ERA-PG or FP7), since this enabling technology constitutes the basis for implementing the SRA.

4.2. Advanced approaches to plant breeding

Submissions assembled in this topic described complementary approaches to improving plant breeding strategies. These projects were aimed at making plant breeding more rapid and direct and at increasing the use of a greater degree of genetic diversity. Some research themes aimed to take advantage of increased genomic information to access and manipulate a wider range of genetic diversity using more rapid and direct methods. Several projects aimed to deepen understanding of biological processes generating genetic diversity, and to improve methods for generating and using novel genetic diversity in major European crops. These projects were generally appropriately linked to work aimed at both developing genome-related data and generating useful diversity. The research community appears to be well prepared to exploit the rapidly expanding genomic diversity data sets in model and crop species for developing innovative enabling technologies for crop improvement. This work therefore makes key contributions to challenges 1 -3.

For research into the maintenance of polyploids and heterosis only one proposal, focusing on apomixis, was identified in this survey.

4.3. Novel uses of genomic diversity

Such submissions were aimed to conduct research using genetic diversity in a range of plant species that links evolution, ecology, chromosome structure and polyploidy. The proposed work was related to that in 2 above and draws directly from work in area 1. Several projects aimed to discover key agronomic genes involved in selective adaptation and domestication in different groups of plants. Several aimed to

gain a more detailed knowledge of evolution, adaptation and speciation by analysis of genome sequence differences, genome duplication and repeat elements. This work generates concepts and tools to identify key genes underlying environmental adaptation and domestication and therefore contributes directly to future sustainable crop production during climate change. It also bridges work in models and crops and links genomics to ecology, evolution and biodiversity.

The survey did not elicit proposals to survey and catalogue the genetic variation underlying biodiversity.

4.4. Improved GM technologies

These proposals aimed to conduct a wide range of work to make gene transfer more direct, efficient and predictable in a wider range of crops. Some projects aimed to improve gene replacement methods- an area of European excellence. Other projects aim to explore the social and ethical aspects of this technology, which has led to societal concern in the past. By enabling precision genetic engineering, the vast amount of new knowledge about individual genes can be used for crop improvement and new uses for cultivated plants within a framework aimed at establishing a greater degree of public acceptance of GM processes.

One gap in the planned work was that aimed at identifying new promoters for GM crops, particularly to meet social and environmental regulation.

4.5. Multi-level high- precision phenotyping.

Networks giving rise to this topic aim to conduct a wide range of research the development and application of novel methods and instrumentation such as non-invasive methods, and establishing facilities for the high-throughput quantitative measurement of biological processes. These approaches will better assess agronomic and consumer-related traits, remove a bottleneck in plant improvement in conjunction with genotyping methods, and relate phenotypes to underlying physiological and metabolic processes. These projects need to be associated with advances in computational biology for data management and modelling to link diverse data. These projects provide major support for the objectives in 1-3 above.

4.6. Integrative or systems biology

Although this is an emerging field in plant biology the projects were ambitious in scope and aimed to develop an integrated understanding of a variety of processes such as metabolic flux and signalling mechanisms. In the longer term this area has the promise of helping to understand the mechanisms underlying complex traits such as yield and environmental interactions. It also has the potential to structure the research community by developing and using new data standards and linking previously disparate research fields. Despite the highly challenging nature of this emerging field, the research community appears to be prepared to conduct integrative and multidisciplinary research on complex traits such as yield and environmental adaptation. This research will provide the scientific foundations for future improvements of these traits across all crop species and thus contribute to challenges 2 and 3.

4.7. Computational Biology and modelling biological processes.

The projects addressed a wide variety of key issues in plant research, including modelling development, developing platforms and ontologies for comparative genomics and developing databases for integrating knowledge about genes and their functions. It was anticipated that more projects in this field would have been submitted to the survey, including proposals to continue the operation of existing databases and resource centres. One possible explanation is that a significant proportion of proposals in this field would be for generic software development for all organisms. Nevertheless the central importance of this field for all plant biology suggests that this area requires additional stimulation.

The long term maintenance of stock and resource centers and access to high quality databases is of fundamental importance for plant research. However, the survey did not identify any specific responses in this field.

4.8. Basic Plant Processes

Numerous projects aimed at increasing fundamental knowledge were categorised into 11 broad themes representing a wide range of cellular processes.
Possible research themes identified from project submissions

4.8.1 Chromatin organisation and its role in epigenetic regulation of development and environmental responses.

These proposals reflected the current interest and excitement in this field and show that more basic research is needed to understand how the genome is regulated. The survey shows that the research

community is well prepared to meet this challenge. The areas covered include understanding global gene expression, the role of chromatin reorganisation in development and environmental responses, and epigenetics of crop plants. As chromatin regulation is centrally important, work in this field will influence all aims in 1-3.

4.8.2 From transcription networks to the RNA world

RNA plays a central role as a regulator of gene expression, as signal molecules and in defence responses in addition to its function as mRNA. The central importance of this field was recognised in several projects submitted to the survey covering a wide range of areas, including transcription networks regulating mRNA accumulation, RNA processing and RNA surveillance systems in models and crops. These projects link closely with planned work in chromatin organisation and underpin work in many other fields.

4.8.3 The protein world

The systematic analysis of protein structure, function, location and interactions is at the frontiers of building an integrated view of cellular processes. In other organisms such as yeast and *C. elegans* there are systematic efforts to determine protein localisation and interactions. However, only two proposals with limited scope were submitted to the survey. This may indicate that the large proteomes of plants are perceived as a barrier and that the analytical tools required are not yet available.

The survey responses show there is an urgent need for work in several aspects of plant protein science, in particular to contribute to larger-scale systematic analysis of proteins. Work in this field has a radical potential to transform the current understanding of plants.

4.8.4 Regulation and integration of metabolic transformations

These submissions addressed one large- scale objective and several specific pathways and processes. Considering that plant metabolism is the foundation for food and feed, and that very little is known about metabolic networks that are integrated with other cellular functions, the limited scope and ambition of the responses to the survey showed the research community should tackle more creative and ambitious goals in this field. This type of research is needed to support objectives in 1-3.

4.8.5 Synthesis, composition and properties of the plant cell wall.

The plant cell wall is the source of most biomass and should be the focus of intensive integrated research in grasses and other crop species. The cell wall is also the location for cellular communication and morphogenesis and is therefore important for understanding these basic processes. One project addressing one type of cell wall component was submitted to the survey.

This response did not match the emerging importance of the field, the potential for major advances using genomics and cell biology, and the potential for an integrated approach to developing new crops for biomass production. The survey indicates the research community should re-assess its approach to this field.

4.8.6 Capture and use of solar energy, carbon dioxide, water and nutrients

Plants are the source of the vast bulk of renewable biomass through the capture of light energy and its conversion to fixed carbon. Several large submissions addressed energy capture from sunlight in both plants and algae and the efficiency of photosynthesis.

The survey indicates that more research in new topics in this field should be considered by the research community, especially integrated multidisciplinary approaches. These include integrating metabolic and physiological studies to understanding how assimilation is optimised at the whole- plant and community level, and how environmental conditions limit biomass production.

4.8.7 The dynamic cell

Several projects addressing a wide range of basic cellular processes such as the control of cell division, the cytoskeleton and cell polarity were submitted to the survey. An increased understanding of cellular processes opens the route to both increased knowledge of how biological processes are integrated to achieve cellular function and to altering crop plant performance- for example by controlling organ shape and size.

4.8.8 Signalling within cells and between cells, tissues and organs

Projects addressing ambitious objectives were submitted to the survey. Communication is fundamentally different in vascular plants compared to animals, as plants have thick cell walls and different circulatory systems that connect across long distances. Communication is essential for multicellularity and underlies all aspects of growth, development and environmental interactions. The processes involved in linking

activities in different parts of plants are the predominant subject of the submitted projects. In general work in this field is commensurate with its importance.

4.8.9 The integration of growth with metabolism, environment and development

Considering the potential variety of work that could be conducted in this field that response is disappointing, but several aspects of work on growth and development are covered in other topics. Plant growth is highly dependent on environmental conditions, and plants are exquisitely adapted to grow in diverse conditions. Fundamental questions such as how growth is limited in adverse conditions are starting to be answered, and the application of this knowledge will make key contributions to sustainable productivity. Research themes aimed at discovering the mechanisms linking growth to development (e.g. though spatio-temporal control of cell division coupled to long-range signalling) and the links between metabolism and growth, are required to tackle this key fundamental question. *These opportunities need to be addressed by a wider range of projects.*

4.8.10 Plasticity of plant morphogenesis and development: embryogenesis, seed development, root and shoot architecture, flowering

Understanding how the different cells and organs of plants arise continually from apical meristems, and understanding how the body plan of plants is established during the early stages of embryo development are of fundamental interest in biology. This is a very productive field in plant biology. These projects aim to tackle how organs are formed and to model how environmental factors modulate development. Other areas of great interest include how environmental signals control all aspects of development and understanding the mechanisms in crop plants. There is a far wider range of excellent research in plant development that could have been submitted to the survey.

8.11 Senescence and Cell Death

Plant cells and organs undergo a seasonal redistribution of resources and developmentally programmed death, and localised cell death responses are also invoked to combat pathogen spread. Projects focussed on the mechanisms controlling senescence of organs in models and crop species. A deeper understanding of the mechanisms controlling senescence have the potential to increase the growing period in different environments, leading to improved yield and biomass production. The number of projects submitted to the survey was proportionate to the relevance of the research topic.

Members of the panel

Marc Zabeau	VIB, BE	(Panel chair)
Mike Bevan	JIC, UK	(Panel rapporteur)
Mark Stitt	MPIMP Golm, DE	
Francesco Salamini	IT	

Date of panel meeting

6.7.06

Annex Detailed information on the submissions that gave rise to the research topics articulated in this report

Information for the entire survey and breakdown per Challenge of the Strategic Research Agenda “Plants for the Future”

Research topic	Number of submissions	Budget indicated in the submissions		Countries	
		Total in k €	Ranging from xx to xx k €	Submitting the proposals	Indicated as partners in the submission
Entire Survey	**271**	**1 374 454**	**74 – 50 000**	**UK(71), IT(39), DE(36), FR(30), NL(19), BE(15), ES(14), CH(7), DK(7), PT(5), FI(5), AU(4), NO(3), SE(3), RUS(3), PL(2), CZ(1), IS(2),EE(1), BU(1),OTHER (1)**	**DE(1944), UK(1688), FR(1663), IT(963), ES(924), NL(886), DK(404), BE(308), FI(303), CH(293), SE(258), HU(230), PL(212), AU(206), OTHER(183), PT(148), CZ(133), SAF(131), NO(59), GR(58), EE(51), IS(39), IR(31), RUS(34), CHI(27), USA(26), NZ(25), RO(25), CAN(10), LIT(9), AUS(7), ICE(6), TU(6), SL(4), BU(4), CY(3), UKR(2), BRUS(2), VIET(1), CRC(1), COL(1), PER(1), BOL(1)**
Challenge 1. Food and feed	32	141 525	85 – 18 000	IT(10), UK(3), DE(3), ES(4), NO(2), NL(2), AU(2), FR(2), DK(2), PT(1), BE(1)	DE(39), UK(37), FR(29), IT(29), ES(24), NL(13), BE(11), DK(10), AU(9), PL(7), CH(6), SE(5), FI(5), HU(4), PT(4), OTHER(3), GR(3), EE(2), RO(2), SAF(2), CZ(1), IR(1), NO(1), SL(1), CY(1), TU(1), NZ(1), USAF(1), CHI(1)
Challenge 2. Sustainability	108	534 755	74 – 50 000	UK(26), IT(19), FR(15), DE(10), NL(9), CH(5), DK(4), SE(2), BE(4), ES(4), RUS(2), PL(2), PT(1), EE(1), FI(1), BU(1), OTHER(1), AU(1)	DE(820), FR(730), UK(679), ES(408), IT(395), NL(389), DK(160), FI(138), CH(123), BE(114), HU(103), SE(99), OTHER(88), AU(79), PL(77), SAF(64), PT(61), CZ(48), EE(22), GR(22), NZ(12), CHI(13), NO(11), RO(11), RUS(11), USAF(10), IS(6), AUS(1), ICE(1)
Challenge 3. Green Products	34	212 574	524 – 36 000	UK(6), DE(5), BE(5),NL(5), FI(4), ES(3), FR(2), DK(1), IT(1), RUS(1), OTHER(1)	DE(51), UK(32), FR(29), IT(28), NL(28), BE(21), SE(14), ES(12), FI(9), DK(7), IR(4), RUS(4), AU(3), CH(3), IS(3), HU(2), NO(2), OTHER(2), PL(2), GR(2), CZ(1), EE(1), PT(1), RO(1), BU(1), TU(1), LIT(1), VIET(1), CRC(1), COL(1), PER(1), BOL(1)
Challenge 4. Basic Research	97	485 600	400 – 25 000	UK(36), DE(18), FR(11), IT(9), BE(5), NL(3), PT(3), ES(3), CH(2), CZ(2), IS(2), NO(1), AU(1), SE(1)	DE(1034), UK(940), FR(875), IT(511), ES(480), NL(456), DK(227), BE(162), CH(161), FI(151), SE(140), PL(126), HU(121), AU(115), OTHER(90), PT(82), CZ(83), SAF(65), NO(45), GR(31), IS(30), EE(26), IR(26), RUS(19), RO(11), USAF(15), CHI(13), NZ(12), CAN(10), LIT(8), AUS(6), ICE(5), TU(4), BU(3), SL(3), CY(2), UKR(2), BRUS(2)

The duration of the proposed projects ranged from 1 to 5 years. Few submissions did not include several countries and were not included in the table.

Detailed information per research topic sorted by challenges of the Strategic Research Agenda

Research topic	Number of submissions	Budget indicated in the submissions		Countries	
		Total in k €	Ranging from xx to xx k €	Submitting the proposals	Indicated as partners in the submission
Details to submissions to Challenge 1 – Food and Feed					
1.1. Food health and safety	16	67 840	200 – 18 000	IT(8), DE(2), NO(2), ES(2), AU(1), NL(1)	IT(24), DE(23), ES(16), FR(15), UK(12), AU(8), NL(8), PL(5), SWI(4), DK(4), BE(4), SE(3), FI(3),HU(3), PT(2), RO(2), GR(2), EE(1), IR(1), OTHER(1), SL(1), CY(1), TU(1), NZ(1), USAF(1), SAF(1), CHI(1)
1.2. Nutritional quality	11	57 185	85 – 15 000	UK(2), FR(2), DK(2), NL(1), PT(1), IT(1), BE(1), ES(1)	UK(15), DE(13), FR(10), BE(6), DK(6), ES(4), IT(4), NL(3), FI(2), SE(2), CH(2), AU(1), CZ(1), EE(1), NO(1), OTHER(1), PT(1), PL(1), GR(1),SAF(1)
1.3. Nutraceuticals and food products for specialized consumers	4	15 500	1 000 – 8 500	IT(1), AU(1), UK(1), DE(1)	UK(10), FR(4), DE(3), ES(3), NL(2), BE(1), HU(1), IT(1), OTHER(1), PT(1), PL(1)
1.4. Feed safety and nutritional quality	0 See 1.1 submissions were covering food and feed, focusing on food				
1.5. Cross-cutting themes	1	1 000	1 000	ES(1)	ES(1)
Details to submissions to Challenge 2 – Sustainability					
2.1. Improving plant productivity and quality	64	328 538	74 – 17 000	UK(14), FR(10), IT(7), NL(6), DE(6), CH(5), DK(3), ES(3), BE(2), EE(1), RUS(1), PL(1), PT(1), OTHER(1)	DE(70), FR(64), UK(59), ES(36), IT(35), NL(35), DK(14), FI(12), CH(11), BE(10), HU(9), SE(9), OTHER(8), PL(7), AU(7), IS(6), PT(5), CZ(4), GR(2), EE(2), NO(1), RO(1), RUS(1), CH(1), AUS(1), ICE(1)
2.1.1. Biotic Stress	37	185 448	74 – 17 000	UK(7), FR(6), NL(6), IT(6), DE(3), DK(2), CH(2), ES(2), EE(1), BE(1), RUS(1)	FR(39), UK(32), DE(28), NL(28), IT(17), ES (16), DK(8), OTHER(8), FI(7), SE(6), CH(6), HU(6), AU(4), BE(4), EE(2), PL(2), CZ(1), NO(1), RO(1), RUS(1), AUS(1)
2.1.2. Abiotic stress	12	45 815	800 – 11 200	UK(2), CH(2), DE(2), IT(1), PL(1), BE(1), ES(1), DK(1), FR(1)	DE(17), ES(14), IT(13), UK(12), FR(12), NL(5), PL(5),BE(4), CH(4), IS(4), DK(3), SE(3), AU(2), FR(2), FI(2), PT(2), GR(2), HU(1), CZ(1)
2.1.3. Yield improvements	15	97 275	500 – 15 000	UK(5), DE(4), FR(3), CH(1), PT(1), OTHER(1)	DE(25), UK(15), FR(13), ES(6), IT(5), PT(3), FI(3), DK(3), BE(2), CZ(2), HU(2), NL(2), IS(2), CH(1), AU(1), CH(1), ICE(1)
2.2. Optimizing agriculture to further reduce its environmental impact	30	168 950	350 – 50 000	UK(7), IT(7), DE(4), NL(2), FR(2), SE(2), PL(1), BE(1), DK(1), FR(1), AU(1), FI(1)	UK(33), IT(25), DE(25), NL(17), FR(15), ES(13), BE(8), PL(7), SE(7), GR(6), DK(6), OTHER(6), CHI(5), PT(5), NO(4), AU(3), RUS(3), CH(3), CZ(2), EE(2), FI(2), TU(2), HU(1), IR(1), SL(2), CROA(1), SERV(1), AUS(1), IS(1), ARG(1), PAK(1)

Research topic	Number of submissions	Budget indicated in the submissions		Countries	
		Total in k €	Ranging from xx to xx k €	Submitting the proposals	Indicated as partners in the submission
2.3. Enhance and protect diversity	6	27 840	500 – 20 000	IT(2), FR(2), BE(1), BU(1)	FR(6), ES(5), OTHER(5), UK(4), DE(4), IT(4), HU(3), NL(4), BE(2), AU(1), CZ(1), IR(1), PT(1), SE(1), BU(1), NZ(1), CHI(1), IS(1), ARM(1)
2.4. Enhancing the aesthetic value and sustainability of the landscape	8	9 425	500 – 3 500	IT(3), UK(2), NL(1), ES(1), RUS(1)	IT(8), UK(4), FR(4), NL(3), DE(3),RUS(3), ES(3), NO(2), CH(2), EST91), FI(1), HU(1), OTHER91), SE(1), GR(1), SL(1), SK(1)
2.5. Other issues (climatic changes)					
Details to submissions to Challenge 3 – Green Products					
This breakdown is not available as the panel did not link the submissions to the research topics					
Details to submissions to Challenge 4 – Basic Research					
4.1. Creation of advanced genomic resources	14	109 500	1 300 – 25 000	UK(8), FR(4), ES(1), DE(1)	UK(61), DE(29), FR(28), DK(23), IT(19), PL(16), NO(14), ES(12), CZ(11), NL(10), CH(9), HU(8), IR(7), BE(7), SE(6), IS(5), LIT(4), FI(3), CAN(3), PT(3), RUS(3), AUS(2), ICE(2), TU(2), AU(2), EE(1), CY(1), BU(1), USAF(1), UKR(1), BRUS(1)
4.2. Advanced approaches to plant breeding	5	25 400	2 500 – 12 000	DE(2), UK(1), IT(1), CZ(1)	DE(19), IT(15), UK(7), FR(7), NL(6), AU(5), CZ(3), ES(2), SE(2), CH(2), DK(1), IR(1), SL(1), IS(1)
4.3. Novel uses of genomic diversity	11	41 860	450 – 10 000	DE(3), FR(3), UK(2), IT(2), PT(1)	DE(19), UK(17), IT(14), FR(10), ES(8), PT(6), AU(4), BE(4), IR(4), SE(4), DK(3), GR(3), FI(3), IS(3), CAN(2), NL(2), NO(1), CZ(1), PL(1), USAF(1)
4.4. Improved GM technologies	9	45 000	1 000 - 10 000	UK(4), NL(2), IT(2), IS(1	DE(11), UK(10), NL(9), FR(7), IT(5), IR(3), DK(3), IS(3), CH(2), OTHER(2), PL(1), HU(1)
4.5. Multi-level high-precision phenotyping	4	28 900	400 – 20 000	DE(2), BE(1), IT(1)	DE(7), FR(3), UK(3), IT(2), NL(2), BE(2), OTHER(1), PL(1), ES(1), CH(1), SE(1)
4.6. Integrative or systems biology	4	25 500	6 000 - 7 500	DE(3), UK(1)	DE(11), UK(9), FR(4), NL(3), AU(2), SE(2), BE(1), CZ(1), DK(1), HU(1), IT(1), CH(1)
4.7. Computational Biology and modelling biological processes	7	39 100	600 - 18 000	FR(3), DE(2), UK(2)	DE(11), FR(9), UK(6), BE(5), NL(4), RUS(2), SE(1), ES(1),NO(1), OTHER(1)
4.8. Basic Plant Processes	43	170 340	700 - 18 000	UK(18), DE(5), BE(4), IT(3), PT(2), ES(2), CH(2), NO(1), AU(1), NL(1), FR(1), SE(1), CZ(1), IS(1)	UK(73), DE(51), FR(39), ES(26), NL(22), BE(18), IT(17), CH(14), PL(14), SE(13), DK(12), AU(12), IS(6), CZ(4), NO(3), PT(3), GR(3), EE(2), IR(2), FI(1), HU(1), SL(1), BU(1), USAF(1), SAF(1), AUS(1)

Research topic	Number of submissions	Budget indicated in the submissions		Countries	
		Total in k €	Ranging from xx to xx k €	Submitting the proposals	Indicated as partners in the submission
4.8.1.Chromatin organisation and its role in epigenetic regulation of development and environmental responses	6	15 060	1 000 - 3 600	CH(2), UK(1), ES(1), PT(1), BE(1)	UK(12), ES(7), FR(6), PL(5), CH(5), AU(4), DE(4), NL(3), IR(2), IT(2), HU(1), DK(1), BE(1), SE(1)
4.8.2. From transcription networks to the RNA world	6	27 200	1 000 - 18 000	UK(5), IT(1)	UK(12), DE(10), IT(7), FR(5), ES(4), NL(4), PL(2),DK(2), AU(2), BE(1), SE(1), CH(1), IS(1)
4.8.3.The protein world	2	10 000	3 000 - 7 000	DE(1), BE(1)	DE(6), FR(5), DK(4), UK(4), CH(3), PL(2), BE(1)
4.8.4. Regulation and integration of metabolic transformations	4	10 200	700 - 4 500	UK(2), ES(1), IT(1)	UK(4), DE(3), ES(3), FR(3), IT(2), CH(2), BE(1), DK(1), NL(1)
4.8.5. Synthesis, composition and properties of the plant cell wall	1	6 000	6 000	UK(1)	FR(3), UK(2), BE(1), SE(1)
4.8.6. Capture and use of solar energy, carbon dioxide, water and nutrients	6	24 900	1 800 - 10 000	DE(2), UK(2), BE(1), SE(1)	UK(7), DE(6), FR(6), SE(3), BE(2), ES(2), NL(2), NO(2), PT(2), PL(2), USAF(1), AUS(1), AU(1), CZ(1), EE(1), IT(1), CH(1)
4.8.7. The dynamic cell	4	7 730	1 290 - 2 500	UK(1), DE(1), CZ(1), PT(1)	DE(8), UK(6), NL(4), IT(3), CZ(3), AU(2), FR(2), BE(1), EE(1), PT(1), PL(1), GR(1)
4.8.8. Signalling within cells and between cells, tissues and organs	3	24 900	8 000 - 8 900	AU(1), DE(1), UK(1)	UK(7), DE(4), AU(3), ES(3), IS(3), FR(2), DK(1), NL(1), PL(1), GR(1)
4.8.9. The integration of growth with metabolism, environment and development	3	12 000	2 000 - 7 000	UK(2), DE(1)	UK(6), BE(4), DE(3), FR(2), IT(1), NL(1), SE(1), CH(1)
4.8.10. Plasticity of plant morphogenesis and development: embryogenesis, seed development, root and shoot architecture, flowering	3	9 300	2 000 to 5 000	NO(1), FR(1), BE(1)	DE(4), UK(4), BE(3), ES(3), FR(3), DK(2) SE(2), FI(1), IT(1), NO(1), CH(1)
4.8.11. Senescence and Cell death	5	23 050	2 000 - 12 500	UK(3), NL(1), IS(1)	UK(9), NL(6), ES(4), SE(4), BE(3), DE(3), FR(2), IS(2), DK(1), PL(1), SL(1), BU(1), SAF(1)

Country codes used :

AU	Austria	CY	Cyprus	IR	Ireland	RO	Romania
AUS	Australia	CZ	Czech Republic	IS	Israel	RUS	Russia
BE	Belgium	DE	Germany	IT	Italy	SAF	South Africa
BOL	Bolivia	DK	Denmark	LIT	Lithuania	SE	Sweden
BU	Bulgaria	EE	Estonia	NL	The Netherlands	SL	Slovenia
BRUS	White Russia	ES	Spain	NO	Norway	TU	Turkey
CAN	Canada	FI	Finland	NZ	New Zealand	UK	United Kingdom
CH	Switzerland	FR	France	PER	Peru	UKR	Ukraine
CHI	China	GR	Greece	PL	Poland	USA	U.S.A.
COL	Colombia	HU	Hungary	PT	Portugal	VIET	Vietnam
CRC	Costa Rica	ICE	Iceland				