Italian Technology Platform

Plants for the Future

IT-Plants

Vision Document and
Strategic Research Agenda
for 2020 and beyond

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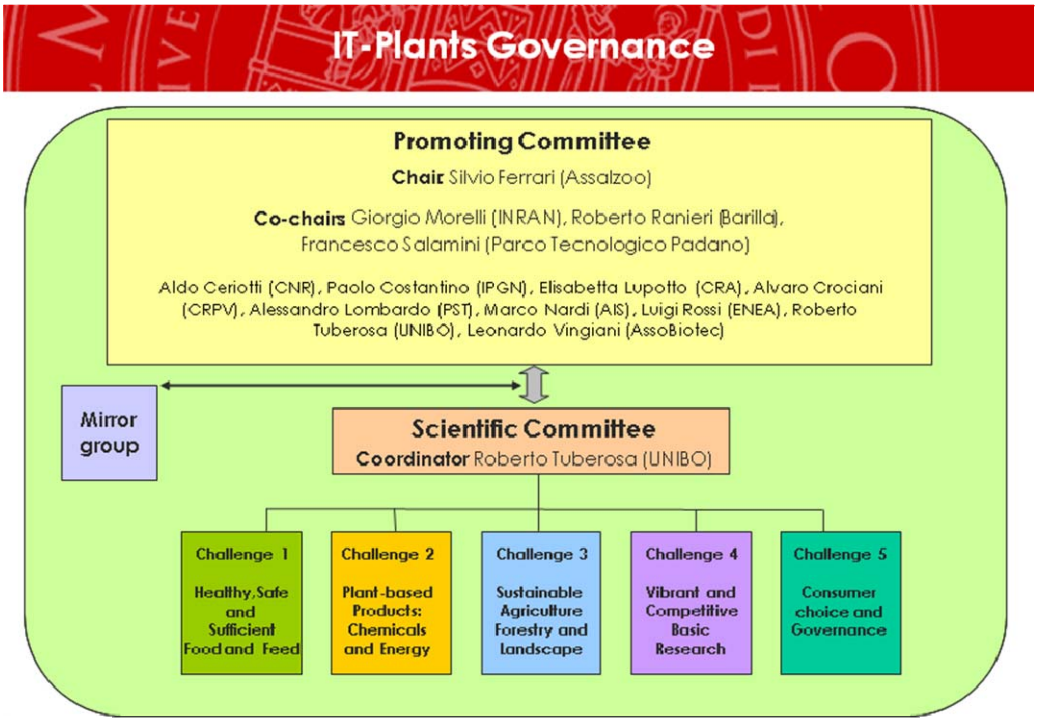
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Challenge 5
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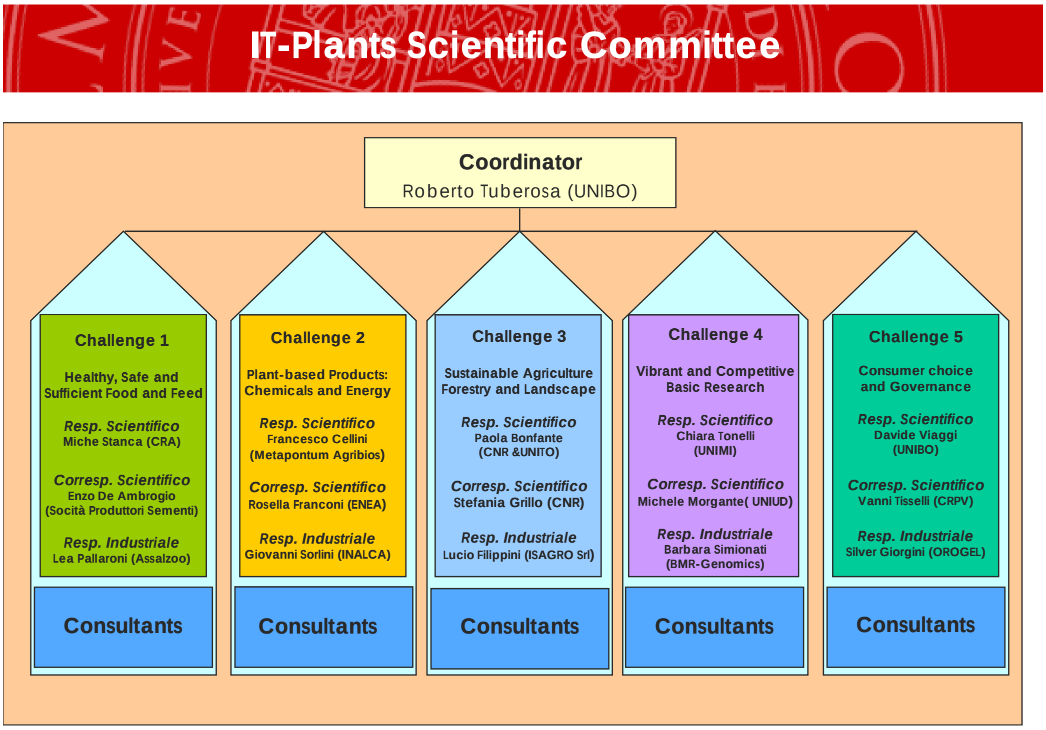
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Healthy, safe and sufficient food and feed

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The first version of the "Vision Document and Strategic Research Agenda for 2020 and beyond" was drafted by the following colleagues at the University of Bologna:

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Their valuable contribution is gratefully acknowledged

Italian Technological Platform
“Plants for the Future”
IT-Plants

Challenges and opportunities in plant research for the agro-food and agro-industry chains in Italy

Introduction

Plants for the Future is a stakeholder forum on plant genomics and biotechnology that was initiated by the European Commission in 2004. At the EU level, the Platform is coordinated by EPSO (European Plant Science Organization) and EuropaBio, and has members from industry, academia and the agricultural sector. It provides a short-, medium- and long-term vision for Europe’s plant agricultural sector and sets out a consensus on the research needed to fulfill the vision. The Strategic Research agenda (SRA) identifies five challenges to which the plant sector can contribute:

- Healthy, safe and sufficient food and feed;
- Plant-based products for chemicals and energy;
- Sustainable agriculture, forestry and landscape;
- Vibrant and competitive basic research;
- Consumer choice and governance.

The recent food crisis at the international level has highlighted the vulnerability of our food production chain and the necessity to boost yield per unit of arable land in order to contain production costs while reducing the environmental footprint of agricultural practices and ensuring healthier products and a profitable income to farmers. The latest changes in global economy, the enhanced sensibility of society to sustainability issues coupled with a growing concern about climatic changes have suddenly burdened agriculture of novel and challenging duties. The release of new, improved cultivars will remain the best option for meeting the future challenges to produce sufficient, healthy and safe food, feed, fiber and biofuels. Tailoring better cultivars will increasingly rely on an interdisciplinary approach based on the integration of genomics and biotechnology with breeding programs.

The Italian scenario

In Italy, the scenario of plant research is particularly fragmented, with numerous groups that are active at the regional and national levels. However, these groups are scarcely coordinated and often lack the critical mass required to successfully compete at the EU level and to attract the interest of the private sector. Conversely, the private sector seeks collaborations with public institutions mainly for short-term goals rather than for more strategic and long-term goals. The 30 private companies listed in the area of plant biotechnology in 2007 represent only 13% of all companies active in R&D in biotech-based products in Italy. Therefore, there is good potential to develop new companies, provided that the right legal framework to protect intellectual property is in place.

The Italian Platform “Plants for the future“ (IT-Plants) aggregates relevant private and public stakeholders in order to (i) elaborate the strategic vision and guidelines for future research projects on plants of interest to our agro-food sector, and (ii) provides opportunities for product innovation through private-public partnerships. The main industries that will benefit directly from the activities of IT-Plants are those involved in the release of improved cultivars and those engaged in the production of food, feed, drinks, fiber, biofuels and chemical and pharmaceutical compounds.

A well-developed seed industry is a prerequisite for an effective exploitation of research findings of plant science. In Italy, only ca. 10% of the ca. 350 companies active in the production and trading of seed are engaged in the breeding activities required for the release of improved cultivars. The commercial balance is negative because seed imports clearly prevail on exports. Most seed companies are small-sized and, with only few exceptions, suffer from a chronic lack of investment in research and poor collaboration with the public sector. This, in turn, limits the possibility of innovation and breeding activities required to meet farmers’ needs and increases the presence of foreign varieties in sectors typical of the Italian agriculture. Differently from other EU countries where large, coordinated national platforms on plant genomics have been developed, Italy has not yet developed such a platform and, in a broader context, the research infrastructure needed to take full advantage of the results derived from the application of the breakthroughs in plant science. In Italy, the average farm size is rather small (ca. 5 ha), with many farms engaged in the production of products typical of the Mediterranean diet. These farms will face an increasing competition from the global market. Maintaining a sufficient level of competitiveness of small-sized farms will require an improvement of product quality and production levels through innovative solutions. Improving the yield potential and adaptation of the species typical of the Mediterranean diet, generally recognized as the ambassador of the “Made in Italy” in the world, will preserve the identity of our agriculture system while increasing its competitiveness.

In Italy, the agro-food sector (including the production of feed, food, drinks, fiber and biofuels) is one of the main pillars of our economy, representing the second manufacturing industry of the country. In 2007, the turnover of the agro-food sector has been estimated to be equal to Euro 113 billion, of which 18 billion in export. Industry buys and processes 70% of the national agricultural raw materials. Imports account for ca 15% of our needs (up to 50% for bread wheat), a figure that is particularly worrisome in view of the recent food crisis and its repercussions on prices and availability of cereals, the main component of our diet.

Presently, plant-derived bioenergy contributes to ca. 2% of Italy’s energy requirements. Therefore, a massive effort will be required to meet the EU standards to reach the goal of 25% replacement of non-renewable energy sources with biomass-derived energy by 2030. This formidable challenge can only be met with energy crops with a very high yield per hectare, more efficient in water and nutrient use and with improved compositional quality.

The recent concept of plants as “green factories” provides the basis for new possibilities in medicine, also addressing key issues in developing countries, such as the prevention and treatment of infectious diseases, which is one of the most compelling challenges facing the rapidly expanding world population. Consequently, the healthcare industry will increasingly market new plant-derived therapeutics and diagnostics. Plants have historically been an important source of pharmaceutical products. Currently, 66% of all antimicrobials and 52% of all anticancer drugs are directly or indirectly derived from natural resources. The production in plants of recombinant protein medicines, like vaccines, antibodies, other prophylactic and therapeutic proteins, can potentially address many of the difficulties and challenges posed by existing methods of production. In fact, plant systems can be used for the production of safe and low-cost, sub-unit vaccines that can be formulated either as injected vaccines (using highly purified preparations) or as orally administered vaccines using partially processed plant material. The first plant-produced vaccines, antibodies, as well as prophylactic or therapeutic proteins have already reached clinical trials. Several small and medium enterprises (SMEs) are active in the production of plant-derived chemical and pharmaceutical products, much more so than in other European countries. This high entrepreneurial diversity contributes to creating a highly dynamic economic atmosphere that has a much stronger tendency to generating profit and employment compared to the overall manufacturing sector.

More in general, among the several uncertainties that weigh heavily on a sustainable and profitable production of plant-derived goods, the sharp rise in crude oil and fertilizer price, the dwindling availability of irrigation water and climate change pose new and particularly daunting challenges. Additionally, increasingly unpredictable weather patterns exacerbate the negative impact of environmental constraints on yield stability and product quality.

The way forward

The development of a knowledge-based bio-economy constitutes by far the most challenging and promising opportunity for the Italian agro-food sector in terms of economic, environmental and societal potential. Only the application of the findings of new research approaches and innovation can enable the Italian agro-food chain to face the competition with European and extra-European agricultural systems. This challenge will be even more daunting in view of the decreasing availability of arable land and the necessity to promote a more sustainable and profitable agriculture able to reduce the environmental footprint of farming practices while preserving natural biodiversity and the landscape.

Building a more bio-based economy taking full advantage of the innovations offered by scientific breakthroughs will help to secure food and feed supplies while promoting the production of renewable plant-based energy, wood products and new “green” products. The Strategic Research Agenda (SRA) outlined hereafter provides the guidelines in order to cope with the challenges of the next decades.

The implementation of this SRA will require strong financial commitments from both the public and private sectors. An essential prerequisite will be an increase in the level of research funding to bring it up to international standards. There is now a considerable funding gap between the EU and many of its major commercial competitors, such as the United States and even more so with regard to China and India. In the last decade, public and private funding of plant biotechnology in Europe has stalled, or even dropped. This was largely caused by the public controversy surrounding the risks and benefits of genetically modified (GM) plants and derivative foods. As a result, since 1998 the number of research projects in plant biotechnology in the EU has fallen by 37%, while in the private sector the drop has been over 60%. In Italy, this decrease was more pronounced due to chronic lack of funding and a particularly negative perception of GM-derived plant products. This situation is also affecting classical breeding and the seed industry, which – although not producing transgenic plants – are highly dependent on the progress of biotechnologies. Consequently, our competitiveness depends on how effectively a favourable investment and market environment in plant genomics and biotechnology can be restored. The participation of industry in research will be essential to ensure an appropriate focus on product deliverables. Joint financing with dynamic ratios of public funding and private investment are recommended for specific areas of research that have the potential to generate new added-value products and that require substantial upfront investments in basic research.

As a response to the listed challenges, the SRA of IT-Plants offers a unique opportunity to stimulate and coordinate research and technological innovation of the national agro-food sector in order to strengthen its competitiveness. A balance between the need to safeguard the heritage of tradition and the need to exploit the benefits derived from innovation will provide the underlying guideline for a more profitable and sustainable production of the “Made in Italy” agro-food products.

Challenge 1

Healthy, safe and sufficient food and feed

In affluent countries, the combination of high-fat, energy-dense diets and sedentary behaviour increases the incidence of chronic diseases such as obesity, diabetes, cardiovascular disease, stroke, hypertension and some cancers. Scientific evidence indicates that some food has the potential to prevent the onset of chronic diseases. Therefore, a healthier diet, specifically tailored to target the needs of specific consumers' groups, might reduce the incidence of such diseases.

While Italy almost completely fits the general trends of developed countries, with respect to basic dietary figures (per capita energy and major nutrients intake, age structure and life styles) important differences characterise dietary habits and preferences of Italian consumers. The range of plant-based products consumed in Italy is rather large and some of them (e.g. pasta and bread, tomato-derived products, olive oil, wine, legumes, vegetables, fruits, etc.) are key ingredients for the renowned Mediterranean diet and its beneficial effects on our health.

An area of strategic importance for our diet and for the export of "Made in Italy" typical products is animal husbandry. In Italy, about 4 million cattle, 13 million pigs, 440 million broilers and 35 million turkeys are slaughtered every year. Altogether, more than 8.5 million tonnes of feed for farm animals are produced in Italy every year, with the prevailing portion of such feed mainly accounted for by maize and barley. Nonetheless, our internal production is not sufficient to meet the demand of the feed industry.

Plant science and genomics can help us to identify new health-related compounds and more effectively manipulate key genes and quantitative trait loci (QTLs) for improving yield potential of crops and to develop improved cultivars able to produce more nutritious and healthier food and feed. An adequate translation of the findings of research into new cultivars will require the support of a well-developed and competitive seed industry. The specific goals that will be explored under this challenge are to:

1. Develop and produce sufficient, diversified and affordable high-quality plant raw materials for food products.
2. Produce, trace and control safe plant raw materials for feed and food.
3. Tailor plant raw materials for certain health benefits and specific consumer groups.

4. Produce high-quality, sufficient, affordable and sustainable feed.

Goal one: Develop and produce sufficient, diversified and affordable high-quality plant raw materials for food products

The nutritional value of plants depends on their content in carbohydrates, proteins and oils as well as other essential nutrients (essential amino acids and fatty acids, vitamins and minerals), micronutrients (e.g. iron, iodine, magnesium, zinc, selenium, etc.) and other functional components (also known as secondary metabolites) recognised for their positive impact on human health having antioxidant, anticancer, anti-aging, antibacterial, hepatoprotective and choleretic properties. The absence of anti-nutritional factors is also of great importance. Other factors influencing the quality of plant raw materials and, in turn, food quality, are those determining the sensory and/or processing characteristics. Flavour, colour, texture and aroma are essential characteristics that strongly influence consumer preferences. Factors determining the shelf life of both fresh products and processed food, or the stability of plant raw materials after harvest, are also important.

Goal two: Produce, trace and control safe plant raw materials for feed and food

One crucial issue is the safety of food and feed ingredients and derived products. In this context, the reduction of mycotoxins in cereals will play a paramount role, particularly in maize and wheat production. The presence of mycotoxins in feed and food negatively influences growth and health of animals and humans, causing safety problems and great economic losses. Public awareness of the dangerous effects of mycotoxins has rapidly grown in the past decade. Another major goal in order to increase food and feed safety is to improve the traceability of plant raw materials with complementary approaches. The identification of specific markers for quality or sensory profiles will also improve traceability at each step of the food supply chain.

Goal three: Tailor plant raw materials for certain health benefits and specific consumer groups

In Italy, the increasingly ageing population (20% is over 60-years old) poses a number of health problems that in certain cases could be partially counteracted by targeting the composition of food products. Diabetics might benefit from plant raw materials with a low-glycemic index (e.g. carbohydrates which are metabolised slowly, beta glucans, high amylose, etc.). Plant raw materials for foods enriched with specific nutrients (e.g. omega-3 fatty acids, vitamins and minerals, micronutrients, phytosterols, phenolic acids, flavonoids, etc.) and higher fiber content (e.g. whole grain pasta and bread) might lower nutritional deficiencies and the risk of heart disease and some types of cancer.

Goal four: High-quality, sufficient affordable and sustainable feed

Over the past two decades, global meat production has increased rapidly thus requiring a parallel increase in the production of cereal grain, the main ingredient of animal feed. This situation would greatly benefit from the cultivation of higher yielding cereal crops as well as exploitation of plant biodiversity for sustainable feed production. Annually, the European Union imports some 40 million tons of grain, mostly used as feed. In Italy, more than 8.5 million tonnes of feed for farm animals are produced in Italy every year; the prevailing portion of such feed being accounted for by cereals. Plant genomics research provides novel opportunities for boosting and stabilizing yields in order to ensure a sufficient production and supply of feed. At the same time, growing environmental concerns are pushing agriculture towards more sustainable and environment-friendly practices (e.g. minimum tillage, lower N and P fertilization, no irrigation, etc.).

Strategic Research Agenda of the Italian Technology Platform

Goal one: Develop and produce sufficient, diversified and affordable high-quality plant raw materials for food products

Food quality is a complex and rapidly evolving trait: Consequently, new parameters for quality evaluation taking into account the safety, the nutritional value and the sustainability of production, together with more traditional parameters are now considered. In the past, the contribution of plant-derived food to a healthy diet had been mainly attributed to vitamins, minerals and non-glycemic carbohydrates (the so called “fibre”). Recently, the importance of other food components in the maintenance of human health and prevention of chronic diseases has been highlighted. These components of vegetable foods, generally defined as “phytochemicals” or “bioactive components”, belong to the secondary metabolites of the cell and apart from having functional activity, might influence the sensory and/or processing characteristics of the food itself. Flavour, colour, texture and aroma largely depend on specific phytochemicals, which may influence food characteristics addressing consumers’ preferences. Different species and varieties within species greatly vary in nutrients composition and content, according also to the prevailing agronomic practices (e.g. amount of fertilizers, irrigation, rotation, etc.) and environmental conditions (e.g. occurrence of biotic and abiotic stress). Other factors influencing the quality of plant raw materials and food are those determining the processing characteristics. Factors determining the shelf life of both fresh and processed food, or the stability of plant products after harvest, are also important. One possibility to obtain “functional foods” without adding the selected nutrients/bioactive components during technological transformation of the raw materials relies on the identification of proper sources of raw materials by the selection of cultivars possessing higher concentration of the target nutrient. A systems-biology approach exploiting (i) the information jointly provided by “omics” platforms exploiting natural (e.g. germplasm collections) and/or artificially induced variation, and (ii) the analysis of organoleptic characteristics and composition of plant products will facilitate the identification of the processes leading to the production of key metabolites and nutrients. This information will be vital for the release of nutritionally enhanced cultivars and the production of food well perceived by consumers.

Research challenges:

1. Survey of traditional crops typical for the Mediterranean diet as well as their wild or semi-domesticated relatives for the identification of genotypes with healthier characteristics (e.g. higher micronutrient content, lower anti-nutritional content, etc), and for the production of health-promoting components. Analysis of the association of health-promoting components with sensory quality perception and consumer acceptance.
2. Development of new methodologies to assess fruit and vegetable quality in terms of content of nutrients, absence of anti-nutritional factors and sensory characteristics. Development of new processing methods able to improve the quality of raw material.
3. Identification of the genetic basis of key traits for the production of healthier and higher quality food derived from crops typical for the Mediterranean diet that could prevent or counteract chronic human diseases.
4. Selection of new varieties through conventional breeding and/or non-conventional approaches (marker-assisted selection, TILLING and/or genetic engineering), with healthier characteristics and improved quality.

Deliverables:

1. New methodologies to assess the quality of cereals, fruit and vegetables as to their nutrient content, absence of anti-nutritional factors and sensory characteristics.
2. Genes/QTLs that control the nutritional and organoleptic quality of cereals, legumes, vegetables and fruits typical of the Mediterranean diet.
3. New advanced lines and cultivars with enhanced nutritional and post-harvest characteristics and better consumer acceptance.
4. Plant raw materials, including minor crops, with improved characteristics for the production of nutritionally enhanced and safer food.
5. Innovative agronomic practices and/or production methods able to enhance the content of bioactive compounds in vegetable foods.

Goal two: Produce, trace and control safe plant raw materials for feed and food

In the EU and other developed countries, a major goal is to produce food and feed free of mycotoxins, anti-nutritional factors, heavy metals or man-made xenobiotics (pesticides and other chemicals) that are toxic for animals and humans. The production of cereal-derived food with lower amount of mycotoxins is in particular a major goal. Even in animal husbandry the trend is moving towards the production of healthier meat, dairy products and eggs, starting from safer feed. Additionally, the identification and traceability of specific markers for quality or sensory profiles is of great relevance for plant food raw materials.

Research challenges:

1. Develop improved cultivars to reduce mycotoxins and anti-nutrients in feed and food.
2. Identification of chemical, biochemical, DNA sequences or Near Infra Red profiles which could be used as quality markers and to improve traceability at each step of the food supply chain.

Deliverables:

1. New advanced lines/cultivars for the production of feed and food of animal origin containing less mycotoxins, anti-nutritional factors, heavy metals and pesticides.
2. Wheat genotypes resistant to Fusarium for safe food production.
3. Improved nutritional, technological and organoleptic characteristics of animal products.
4. Increased diversity of plant food raw materials.
5. Improved traceability of plant food raw materials.

Goal three: Tailor plant raw materials for certain health benefits and specific consumer groups

The development of plant-derived food improved for a complex of nutritional factors can open new opportunities for their wider acceptance by consumers. Starch, proteins and fatty acid composition will play an increasingly important role to optimise the diet of groups of consumers affected by specific diseases (e.g. obesity, diabetes, hypercholesterolemia, Coeliac sprue, etc.). In the next decades, advances in nutrigenomic research will provide the means to tailor specific diets to the needs of each individual as related to risk factors, sex, age and caloric intake. Taking full advantage of this knowledge will require a parallel progress in the availability of nutritionally enhanced raw materials for food production. This, in turn, will require a close collaboration between plant scientists, food technologists and nutritionists.

Research challenges:

1. Study of plant diversity, biosynthetic pathways and related genes/QTLs with regard to metabolites (e.g. phenolics, flavonoids, glucosinolates, diterpenes, PUFA, etc.) that might play a role both in the improvement of nutritional value of a plant derived food and in chronic disease prevention.
2. Identification of genes/QTLs influencing (i) composition of starch and rate of carbohydrate release from cereals and potato starch, and (ii) oil composition in oilseed crops.
3. Identification of the molecular and genetic basis of food allergenicity (e.g. gluten, kiwi, etc.).
4. Selection of new varieties through conventional breeding and/or non-conventional approaches (marker-assisted selection, TILLING and/or genetic engineering) for the production of food with higher nutritional value and higher preventive activity.

Deliverables:

1. New sources of raw materials for the production of functional foods.
2. New sources of specific carbohydrates and lipids.
3. Genes/QTLs for the biosynthesis of carbohydrates, lipids, protective metabolites and allergenes.
4. New advanced lines and cultivars for the production of food with improved carbohydrate, lipid and protein composition, and enhanced capacity to prevent chronic diseases.

Goal four: High-quality, sufficient affordable and sustainable feed

Feed quality strongly influences feed utilization efficiency by animals and, as a consequence, their productivity, the environmental impact of farming and the quality of animal products for human consumption. Global production of food of animal origin is increasing worldwide. In developing countries, meat consumption is expected to increase ca. 7% each year during the next decade. Therefore, to contain the increase in price due to an insufficient feed supply a major goal is to boost feed production per unit of cultivated area while lowering its environmental footprint. Achieving this goal will be facilitated by the identification of the relevant genes/QTLs and their targeted manipulation via marker-assisted selection, TILLING and/or genetic engineering for the release of new cultivars. Achieving this goal will require a close collaboration with breeders.

Research challenges:

1. Identification of the genes/QTLs controlling yield potential, water- and nutrient-use efficiency, and resistance to pathogens in feed crops.
2. Selection of new cultivars with high yield potential and high water- and nutrient-use efficiency and resistant to pathogens.

3. Investigations on some “non-conventional” vegetable protein sources to feed pigs, cattle and poultry.

Deliverables:

1. New cultivars for feed production characterized by higher yield as well as higher water- and nutrient-use efficiency and more tolerant to diseases.
2. New cereal cultivars low in linoleic acid in order to improve technological and organoleptic quality of pig meat.
3. Increased use of locally produced feedstuff.
4. Improved nutritional, technological and organoleptic characteristics of animal products.

Challenge 2

Plant-based products: chemicals and energy

Environment friendly bio-based “green” products target new needs of producers, industry, consumers and society. European welfare largely depends on the emergence of new markets and the growth of existing ones, while respecting the environment and responding to society expectations. To this end, critical success factors are the ability of companies to innovate their product portfolio and production processes in line with unmet customers’ 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 renovating their product offerings. The main reason is that new means of extracting, processing or (chemically) modifying raw materials are running out.

Similarly, fossil fuel-based industrial sectors are encountering increasing difficulties in sustaining their business. This is due to diminishing global crude oil reserves and growing public concern about future supply and the environmental impact of burning more fossil fuels. The transition from our current fossil fuel-based industry to a more bio-based industry will have a far-reaching impact on agriculture, industry and society. It is plausible that many breakthroughs may derive from plants and plant-based raw materials with improved or new properties. The underlying concept is that plants will be exploited as a production system in the broadest way imaginable. This might 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 society not only with better, cheaper and safer products, but also with totally new products, production methods, land uses, jobs and ways of living.

Implementation of the GM-regulatory framework specifically tailored for genetically modified non-food crops for plant-based applications, particularly biofuels, constitutes a condition *sine qua non* to ensure a competitive position for Italy in the new bio-economy, avoiding the risk to become dependent once more on imports to meet the targets set out in the EU’s Biofuels Directive. In this perspective and in accordance with EU policies, the specific goals of this challenge are:

1. Biochemical production.
2. Bioenergy and biofuels.
3. Enabling research for plant-based products.

Goal one: Biochemical production

Both society and industry would benefit from exploring the uses of new, renewable plant raw materials with better-performing features or accumulating new compounds. These benefits may range from cheaper, safer or more environment friendly production methods to better products for the consumer. New plant raw materials from conventional and GM plants may include peptides, proteins, fatty acids, biopolimers, oils, starches, fibres and secondary metabolites, with important applications. Accordingly, plants may become a major source for the production of pharmaceuticals in two major ways: as a source of recombinant protein medicines (e.g. vaccines, antibodies and other therapeutic molecules) and as a source of natural products. In both cases, the principal advantages of plant-based production systems are flexibility, scalability and cost. The development of new plant-based raw materials and compounds requires improved knowledge on key biosynthetic pathways and participating genes, on plant response to environmental cues and stress as well as the appropriate enabling technologies. It is fundamental to support a broad range of technological developments (also with the aim to enlarge the national proprietary patents portfolio, particularly in the field of heterologous expression systems) that will enable the Italian bio-based industry to implement the most optimal “green” production system on a local basis. Once more, implementation of the GM regulatory framework for GM non-food crops for plant-based applications, constitutes an essential prerequisite.

Goal two: Bioenergy and biofuels

Sustainable use of plants to produce energy requires a substantial net energy gain. Simulations that take into account all inputs in the plant-based energy generation process tend to show that the net gain currently ranges between negative and a factor two compared with input energy. This is insufficient to play an important role in resolving future energy demands. Therefore, the challenge is to rethink the concept and lower energy input requirements for producing biomass, while maximising energy retention. The ultimate application of this know-how would be the development of an economically competitive, net energy-producing system for the energy industry. Compositional quality of plant biomass will be also relevant particularly for biofuels production where the correlation between biomass composition and fuel overall performances and technological qualities is very strict. Changing the metabolism of plants to produce specific metabolite profiles adapted to the industrial process and product will be a major technological challenge. In order to reach such goals, R&D activities should focus on the screening and evaluation of the productivity and duration of plant cultures - both native as well as of exotic origin - used for energy and/or biofuel production, with the main objective of identifying the species and varieties more promising under different environmental and climatic conditions. An integrated vision of the new bioenergy system, looking from the farming side, can be summarised as follows: 1) Avoiding competition with food crops and research for new crop models; 2) Integration, not substitution of food crops (short-term: integration by annual crops; medium-long term: substitution on marginal lands, perennial crops); 3) Innovation for low-input cultivation techniques (no or minimum tillage, low use of fertilizer, precision farming, no irrigation). In any case, in order to make bioenergy and biofuel really sustainable, it is necessary to improve the greenhouse gas emission balance by reducing emission due to crop cultivation (e.g. machinery use, fertilization, etc.) as well as by converting biomass into energy or biofuels by means of high efficient processes, leading to the total exploitation of the whole biomass (for example by producing “second generation” liquid biofuels).

Goal three: Enabling research

Specific case-by-case crop production platforms have to be developed taking into consideration a number of factors: 1) ability to direct post-translational modifications; 2) concentration, extractability and storability of the desired compound; 3) infrastructure requirements (field, greenhouse, growth rooms and fermentors); 4) handling requirements for growing the plants. In case of food or feed crops, that in some cases could show potential advantages as hosts in comparison with non-food plants, additional factors to consider include the segregation of production lines and the preservation of product identity. For crops with economic and environmental potential, methods for genetic transformation will be developed in order to introduce novel traits. Additionally, a detailed understanding of the plant species at a proteomic and metabolomic level is also required. Thus it will be necessary to develop a comprehensive range of genomics toolkits, new technologies for transient or stable expression of the gene encoding the desired green product and technological platforms able to speed up the selection and phenotypic characterization

Strategic Research Agenda of the Italian Technology Platform

The importance of the Fine and Specialised Chemical sector is connected with the strategic role it plays as a provider of intermediate products that are then employed in a whole range of different kinds of manufacturing: in the food industry, the car industry, textiles, paper, shoes, clothing, electronics, as well as in the chemical and pharmaceutical industries, plastic manufacture, and many others. The chemicals market in Italy is no newcomer to investments made by foreign multinational companies: 35% of the entire sector’s production can be traced to factories set up in Italy by major international groups. The sector is facing structural competitiveness problems and needs a boost based on innovative products and processes.

The benefits of the uses of new plant-based raw materials may range from cheaper, safer or more environment-friendly production methods to the ability to develop new and better products for the consumer. Plant-based resources can provide far more functionalities than society and industry are currently aware of. These may relate to commodity-scale products and as yet unknown utilities of major plant components, as well as to new uses for materials and molecular components, whether in native form or following post-harvest modifications. These new plant-based raw materials may include peptides, proteins, fatty acids and oils, starches, fibres and secondary metabolites, with applications in the health, nutrition and materials industries.

In general, obtaining advanced plant-based raw materials requires, among other things, that an adequate knowledge of key metabolic pathways and participating genes is developed, together with the appropriate assay methods and enabling technologies.

Goal one: Biochemical production

Plants display an enormous diversity in their metabolic pathways. This opens almost inexhaustible opportunities for the production of plant-based raw materials. With the introduction of ‘nutraceuticals’ and ‘cosmeticals’, consumer product manufacturers may see radical changes in their business. Actually the majority of high-value plant secondary metabolites, currently used by the pharmaceutical, cosmetics, food and other industries, are still isolated from wild or cultivated plant species. However, many of these plants are difficult to cultivate or are becoming endangered due to over-harvesting. On the other hand, the potential offered by processed plant by-products is still unexplored and deserves more attention. Furthermore, the chemical synthesis of plant-derived compounds is often not economically feasible due to their highly complex structures and the specific stereochemical requirements of the compounds. Biotechnological production from plant cell cultures is an attractive alternative but has, so far, had only limited commercial success due to a lack of understanding of the complex multistep biosynthetic events leading to the desired end-product.

In addition to the currently known secondary metabolites, plant cells can be utilized for the discovery and the biosynthesis of new compounds for the agroindustry sector (including fibers, carbohydrates, lipids, peptides or proteins) to add value to chemical diversity of the whole plants. Functional genomics and metabolic profiling offer unprecedented possibilities to explore the extraordinary complexity of plant biochemical capacity.

Italy’s increasingly ageing population, and the expanding demand for “natural” plant-based products (e.g. herbal medicine) calls for a concerted effort in exploring the chemical diversity of wild and cultivated plant species, the biological activity of whole plant extracts and single compounds, and the potential for increasing their yield by biotechnological means.

Research challenges:

1. Develop plant-based raw materials with new and improved functionalities.
2. Utilize a systems biology approach to identify and characterize new bioactive compounds and plant-based raw materials.

3. Screening and selection of new/indigenous plants producing natural pharmaceutical and medicinal compounds.
4. Development of innovative technologies for the efficient production of heterologous proteins in plants.
5. Modification of metabolic pathways for the production of new plant-based raw materials.

Deliverables:

1. New technological platforms for heterologous protein expression in plants.
2. Detailed profiling data ("omics" technologies) of the production of secondary metabolites (e.g. polyphenols such as stilbenes, flavonoids, caffeoylquinic acids, taxanes, alkaloids, tocopherol, etc.).
3. Innovative bioactive compounds with antioxidant, antibacterial (new generation of antibiotics), antifungal, anti-viral, anti-cancer and anti-degenerative properties, produced by medicinal and food plants.
4. Production of nutraceuticals.
5. Production of biochemicals for industrial uses such as fibers, intermediate for biopolimers, fatty acdis for detergents, lubricants, coatings, enzymes, proteins to be used, for example, as safer additives, etc.
6. New raw materials with manifold utilizations in the processing industry, and for technological applications.

Goal two: Bioenergy and biofuels

This bioenergy is currently provided either directly through simple combustion of primarily wood or grain products, or after conversion of agricultural biomass from a variety of plant resources to different liquid and gaseous bio-fuels, such as bioethanol (e.g. from cereal grain and/or residues), biodiesel (from oilseed rape, sunflower and soybean seeds) and biogas (from plant lignocellulose residues). This first generation of crops such as wheat, oilseed rape and sunflower have been optimised for food or feed production, but not for biofuels. Hence, neither the biomass yield and compositional quality, nor the input requirements are optimal. Furthermore, the net energy balance – i.e. the ratio of output to input energy – of these first generation biofuels is far from ideal.

A whole range of novel "green" systems for biomass production will have to be developed with the aim to combine minimal energy input requirements and increased energy retention, and to improve biomass composition to adapt it to the sophisticated conversion technologies and to improve the biofuel performances. Although it is currently hard to predict how these novel systems will work, "out-of-the-box" options (e.g. microalgae-based production systems from marine ecosystems) are expected to play an important role. The long-standing tradition of cultivating poplar in Italy (cultivated according to short rotation cultivations cycles if used for energy production purposes) may also contribute to the biofuel option, as well as cultivation of woody or herbaceous energy crops (e.g. black locust, eucalyptus, giant reed, miscanthus, switchgrass, Jerusalem artichoke, etc.) in replacement of other crops whose production is limited by EU policies (e.g. sugar beet). The key factors for high and stable yield are the availability of water and nutrients to the plant. Most climate change models predict increasingly drier springs and summers within Europe, particularly in Italy. Because most of the growth occurs during this period, increased water-use efficiency is needed to maintain high yields, especially for perennial crops.

In perspective, the production of biomass-derived fuels must meet the sustainability criteria, taking into consideration the environmental impact, the impact on the food production chain and societal acceptance of such energy sources. While the environmental impact of the first generation biofuel crops is substantial, the envisaged improvements in the cost-effectiveness of energy production, namely the reduced input and water requirements, will significantly improve the environmental impact of second-generation biofuel crops. The increased yield and productivity will also reduce the competition with food crops, a particularly relevant issue in Italy where cultivated lands are essentially dedicated to food crops and in view of the decreasing trend in availability of arable land.

In a long-term effort, the economical sustainability of the biomass-based energy production will be ensured by the integral use of the plant biomass, by the means of fractionation and separation technologies (biorefineries), combining the production of biochemicals for agroindustry with energy biomass. This third-generation high-tech energy crops (multi-purpose crops, that produce specific biochemicals, as well as biofuels) will most likely be based on the application of plant biotechnology and genetic modification, which could be inhibited by the rigidity of current GM regulations in Italy/Europe. This problem can be addressed either by developing a new European regulatory framework or by adapting the implementation of the present GM regulation for non-food crops. The mere fact that energy crops will help to mitigate the effects of climate change should be used to raise broad public support and acceptance of GM energy crops.

Research challenges:

1. Assess all current crops for their energy production capacity and identify those adaptations that would improve the current output in a short time-span (“best performers”).
2. Define and improve crop and forest tree species, and their by-products, for the production of bio-energy and biofuels (e.g. bioethanol from cereals, sweet sorghum, Jerusalem artichoke, cereal residues or cellulosic grasses, biodiesel from rapeseed, sunflower and soybean oil, poplar and grasses for use in combined heat and power plants).
3. Improve plant yield per unit surface and enhance water- and nutrient-use efficiency (second generation crops).
4. Identify new, economically competitive “green” systems for energy production (e.g., microalgae).

5. Develop new high-energy plant biomass production systems with minimal energy input requirements (improvement of agricultural practices) and higher energy retention (biorefinery of plant cell wall ‘energy’ polymers such as cellulose and lignin).
6. Develop third-generation “green” systems (plants or microalgae) for coupled production of biochemicals and energy.

Deliverables:

1. New annual and perennial ligno-cellulosic crops for biofuel production, capable of producing high dry matter yields and tailored to the conversion process needs.
2. Structural details of biomass constituents (e.g. cellulose, lignin) and biomass-derived materials.
3. Low-input plant varieties for the production of raw materials suitable for biorefining.
4. Low-input agricultural techniques to maximize the yield and sustainability of bioenergy cropping systems.
5. Microalgae cultures suitable for energy and biochemical production.

Goal three: Enabling research

To optimise plants’ performance as “Green factories” for the production of biochemicals and energy, researchers will have to develop new production systems and crops to obtain commercially sustainable levels. New crops should be mainly non-food crops to ensure an effective separation from the food chain. The target will be to identify the most promising crops as production vehicles, and to optimise storage organs by increasing their size, productivity, supply or other aspects. It will be essential to develop crop platforms optimised for single or multifunctional uses (e.g. perennial grasses, trees and species that have not been developed as crops, but containing interesting compounds). Plant systems will be developed on a case-by-case basis, depending on the target compound for production. They might be plant-based, fermentor-like production systems similar to those conventionally used for recombinant compounds, or they could utilise whole plants. Profiling technologies will reveal the genetic and regulatory mechanisms of the biosynthetic pathways. Development of high-throughput phenomics platforms for a swift characterization is also needed.

Research challenges:

1. Selection of the most appropriate plant species as a function of the specific compound to be produced.
2. Optimising production and accumulation of selected compounds (e.g. enzymes, pharmaceutical and nutraceutical compounds, etc.) in different plants (including cisgenics).
3. Improved technology for the production and extraction for commercial use of prioritised compounds applicable to multiple plants and plant cells.

4. Development of appropriate transformation technologies based on criteria of expression efficiency, profitablity, eco-compatibility and product-identity preservation.

Deliverables:

1. Novel technologies for the transformation of various selected plants.
2. Plants, plant cell and tissue cultures suitable for fermentor-like applications and standard operating procedures (SOPs) for the production of the desired compounds.
3. Plant-derived platforms optimised for single or multifunctional uses.
4. New technologies for extraction and purification of plant bioactive compounds for small-scale or large-scale commercial applications.
5. Standardization of an integrated technology consisting of biomass production, bioreactor fermentation of plant cells and adventitious roots, extraction and purification of bioactive compounds (e.g. polyphenols such as stilbenes, flavonoids, antioxidants, taxanes, alkaloids, etc.), from crops or wild species.
6. Use of more efficient and economically competitive methodologies for the optimization of the fermentative parameters (e.g. substrate, pH, pO_2, stress condition, use of elicitors, etc.) related to plant cell and tissue cultures, so as to channel biosynthesis towards the production of a specific metabolite.
7. Detailed genomic, proteomic, metabolomic and phenomic understanding of candidate plant species.

Challenge 3

Sustainable agriculture, forestry and landscape

Advances in plant sciences and agricultural technologies have increased plant productivity and quality, thus enhancing the quality of life. However, the current scientific challenge is to develop strategies for reshaping the lives of the next generations in a sustainable manner. Sustainability rests in fact on the principle that we must meet the needs of the present without compromising the ability of future generations to meet their own needs. This complex challenge faces contrasting aspects, some of which have particular relevance in Italy: pressing requests of high quality agricultural products coming from different stakeholders, uncertainties originating from climate change, needs for biodiversity protection which also invest forest trees and landscape management.

Agriculture has a variety of impacts on the environment. Plant protection, fertilizers and agrochemical weeding have greatly contributed to the increase in productivity of crops and their utilization will continue in the foreseeable future. However, there is an urgent need to reduce some of the negative impacts of these chemicals, and especially those hazardous to humans and the environment. An obvious integration to agrochemical protection and fertilizing treatments is the exploitation of naturally occurring resistance mechanisms in crop plants and forest tree species as well as the use of symbiotic/associated beneficial micro-organisms. Both strategies require a sound knowledge of the underlying cellular and metabolic processes. In this context, a further possibility is to integrate agrochemicals and non-chemicals products for controlling weeds, insects and pathogens.

The sustainable increase of the productivity of crops and trees requires the development of tools to characterize and monitor biodiversity present in cultivated fields as well as originating from wild areas. A better knowledge of the biodiversity of pests and pathogens is also needed to develop new crop protection strategies. In addition, plant biodiversity can also be used as a resource to domesticate new crops and trees for plantation forests, as well as to broaden the range of available food products.

Another aspect of any effort to improve sustainability should be the enhancement of the landscape. Land should not be viewed solely as a production silo, but rather as a complex interconnecting network and reservoir of natural resources which can be used for human benefit without long-term damage to the biodiversity that underpins all agricultural and forestry production systems. Delivering environmental goods in terms of habitat, biodiversity and landscape attributes is a top priority for Italy, a country recognized worldwide for its artistic and environmental resources and its cultural and historical heritage, all deeply intertwined with the surrounding landscape.

To meet the above-listed challenges, a research strategy based on four general interdisciplinary goals is required:

1. Improve plant productivity and quality.
2. Reduce the environmental impact of agriculture.
3. Preserve and boost biodiversity.
4. Enhance the sustainability of the landscape.

Genomics provides new tools and approaches (e.g. marker-assisted selection) for adequately improving and sustaining productivity and product quality while managing natural resources and protecting the environment. Nonetheless, a tangible impact of the genomics approach on the agro-food chain will only be possible through its effective integration with adequately developed breeding activities. Additionally, even if plant improvement is expected to provide the major contribution, other disciplines and approaches, from agronomy to farm management and from agro-chemistry to crop monitoring, will also contribute to address this challenge in a multidisciplinary fashion.

Goal one: Improve plant productivity and quality
In Italy, sustainable agriculture is receiving increasing attention. Not only does sustainable agriculture address many environmental and social concerns, but it offers innovative and economically viable opportunities for the entire food-production chain. Plant productivity and quality are very complex traits. In order to improve yield, it will be necessary to identify and describe the key-limiting factors through a holistic approach combining genetic, agronomic, biochemical and physiological methodologies that allows us to understand the interplay between genotype and the environment,.

Goal two: Optimise agriculture to reduce its environmental impact
Crops which are more resistant or tolerant to pests, pathogens and weeds, more water- and nutrient-use efficient and more responsive to mycorrhizal fungi are essential for high quality agricultural products that are progressively more requested by several stakeholders. The interest for organic food in Italy over the past decade clearly underlines a growing attention to healthy and high quality food and to agricultural systems relying on innovative crop protection products with non-hazardous effects on humans and the environment.

Goal three: Preserve and boost biodiversity
The third sustainability priority is to preserve, enhance and more effectively exploit plant and microbial biodiversity. We need therefore to better characterise and maintain the biodiversity present in crops and related wild

species including those typical of Italian environments (fields and forests). Although part of our biodiversity lies in the existing collections preserved in genebanks, the vast majority of plants, insects, nematodes, fungi, bacteria and viruses with potentially useful properties remain unexplored. Managing more effectively biodiversity may lead to agricultural practices for controlling pest and plant pathogens more beneficial for the environment.

Goal four: Enhance the sustainability of the landscape
Today, urbanisation is increasingly claiming more land away from agricultural and forest systems, while reservoirs of new arable land are very limited. The management of plant resources plays a major role in defining the landscape, the environmental and amenity value of wild, semi-natural and farmed environments, as well as gardens and parks. Additionally, by the end of this century, global temperatures are expected to increase from 1.5 to 4 ºC. Variations in mean precipitation and in the frequency of intense rainfall have been predicted, and some already drought-prone areas are expected to become drier thus exposing the Italian landscape to new environmental constraints. Enhancing the sustainability of the landscape while improving its aesthetical value will thus require considering both human and natural factors.

Strategic Research Agenda of the Italian Technology Platform

Goal one: Improve plant productivity and quality
Metabolic processes affecting productivity (e.g. primary metabolic processes, metabolite partitioning, translocation and accumulation of storage compounds in harvest products, etc.) should be characterized in depth using new experimental approaches. An important aspect for the improvement of the key genes of crop yield is the identification of factors determining plant architecture (e.g. root architecture, leaf angle, tillering, leaf/stem ratio, ear fertility in cereals, seed size, etc.) and development (e.g. transition from vegetative to reproductive phase, flowering time, etc.). These aspects are crucial, since reproductive failure due to unfavourable environmental factors (e.g. drought, heat, frost, low nutrients, etc.) typically occurring at flowering and/or during the first stage of grain filling is one of the major factor limiting the final yield of many crops. Equally important is a deeper understanding and characterization of the cellular and molecular mechanisms underpinning the growth, adaptation and productivity of trees due to the importance of long-term maintenance of forest health and productivity. Therefore, genetic and agro-technical approaches (e.g. no tillage, deficit irrigation, sowing density, etc.), environmental factors (e.g. nutrient and water availability, etc.) and climatic factors (e.g. drought, heat, salinity, etc.), all affecting yield and quality, should be investigated and managed interactively. A major challenge will be to unravel the complex interplay between genotype and the environment to identify the genetic factors able to stabilize yield and yield quality across different environmental conditions. This will allow to develop

new crop management tools and new plant varieties able to sustain yield under different abiotic constraints.
Meeting the different quality requirements (e.g. composition of proteins, oils, starch, vitamins, micronutrients, fibres, etc.) of the food-feed and non-food industries is another essential component of sustainable agriculture. Comparative genomics, sequencing and bioinformatics coupled with a targeted deployment of the "omics" platforms will provide novel opportunities to identify the rate-limiting steps like genes coding for high quality traits and controlling the metabolism of the compounds of interest. An important prerequisite for quality improvement is the development of analytical tools for monitoring the quality of each plant product. The physiological and molecular analysis of biosynthesis, transport and deposition processes, including new sophisticated methods for non-invasive, *in planta* study of these processes can provide the set of information required. As the environment has a major influence on the composition and quality of storage material, field trial experiments should be performed to relate quality aspects to environmental factors, an issue particularly relevant in Italy given the broad range of environmental conditions occurring from Northern to Southern regions.

A close interaction of plant scientists with breeders and seed companies will be necessary to make sure that the potentiality of research findings is duly translated and incorporated into improved cultivars for the benefit of farmers and consumers.

Research challenges:

1. Identification of the key factors that govern plant architecture and development, reproductive failure, crop and tree productivity and stability under unfavourable environmental conditions.
2. Characterization of farming practices, adaptive traits, structural and regulatory genes and QTLs that influence yield of crops and trees and favour resource-use-efficient agriculture.
3. Improving plant tolerance to drought, heat, salinity and cold temperatures through molecular breeding, TILLING and/or cisgenic approaches.
4. Improving the quality of plant products and reducing the negative impact of factors deleterious to quality.
5. Selection of varieties with improved product quality and adaptation to stressful environments.

Deliverables:

1. New farming practices to otpimise the use of water and nutrients and reduce the environmental footprint of agriculture.
2. Identification and characterization of genes and QTLs providing tolerance to abiotic factors.
3. New cultivars with improved yield and yield stability under environmental constrains, quality and suitable for more sustainable farming practices.

Goal two: Optimise agriculture to further reduce its environmental impact

In Italy, the production of grain, vegetables and fruit relies heavily on the use of agrochemicals. Although new molecules with a reduced environmental impact have already provided encouraging results, further progress is needed. At the same time an improved management of phytoprotectants requires new and more efficient procedures for application and distribution. In fact, a reduced use of agrochemicals will also be reached by reducing the incidence of diseases on plant propagation material through strong phytosanitary certification programs, using biopesticides and, particularly, by pyramiding resistance genes in new cultivars. Pyramiding multiple resistances can be achieved by targeted breeding, supported by molecular markers associated to relevant genes and QTLs.

A number of living organisms are natural predators/parasites preying/growing on pests which they colonize or use as food. Other organisms modify the plant surfaces or the rhizosphere in such a way to create unfavorable niches for pest or pathogens development. The exploitation of this biodiversity is relevant for crop protection. The release of cultivars with enhanced resistance or tolerance to pathogens and pests or with an increased responsiveness to the beneficial mycorrhizal fungi is also a priority objective. The identification of resistance genes and, particularly, QTLs for stress resistance will benefit from a better understanding of biochemical interactions between pests or pathogens and plants and from the knowledge of cellular metabolic processes linked to virulence and pathogenicity determinants. On the other hand, new breeding approaches may generate crop varieties that enhance the agronomic potential of symbiotic associations. Further breeding efforts will be needed to pyramid a comprehensive set of resistances to the plant. To this aim, conventional breeding efforts will be effectively complemented and aided by molecular approaches, such as marker-assisted selection, TILLING and, where needed and practicable, genetic and/or chromosome engineering.

Reducing the impact of agricultural practices will also require a massive effort to improve the water- and nutrient-use efficiency of crops and trees. In Italy, irrigation water (ca. 70% of all water consumed) will become increasingly expensive and unavailable due to local shortages. The forecasted climate changes indicate that these exceptional weather anomalies will become more frequent and extreme. The uptake efficiency of nutrients depends on the crop, its genetic make-up and cultural practices. In the past decades, N-utilisation efficiency has been largely neglected by breeders, since N was relatively cheap and its negative impact on the environment was not duly considered. Development of new irrigation strategies (e.g. deficit irrigation) is essential to improve yield and quality in a sustainable and efficient manner. Improved models for describing and predicting water movement through the complex water-soil-plant-environment system is also critical to both scheduling irrigation practice and managing stress control. In addition, the feasibility of introducing new crops with reduced water/nutritional requirements in unfavorable and resource-limited areas should be considered following a multidisciplinary approach. Genomics and physiological studies will accelerate the identification of the genes and QTLs for the factors that govern nutrient-use efficiency.

Research challenges:

1. Development of improved methods to (i) monitor the performance and persistence of agrochemicals in the field, (ii) study pests and pathogen ecology and epidemiology, weed emergence and competitiveness, and (iii) validate mathematical models for predicting pest and pathogen development to optimize agrochemical applications.
2. Evaluation of targeted strategies to improve resource-use efficiency in different agricultural systems (field, greenhouse, high-input agriculture, low-input agriculture, integrated and organic farming, etc.).
3. Evaluation of sustainable control strategies based on the use of micro-organisms with antagonistic/parasitic activity against pests or pathogens (biopesticides), natural compounds and plant-based products for weed, pest and fungi control, resistance induced by molecules with biotic or abiotic origin.
4. Identification of genes and QTLs able to confer resistance/tolerance to pests and pathogens or to improve the competitiveness against weeds (allelopathy genes) and to increase responsiveness to beneficial mycorrhizal fungi.
5. Improving soil, water and nutrient management techniques, and study of the rhizosphere biota that can influence water and nutrient uptake.
6. Identification of genes/QTLs that control water- and nutrient-use efficiency in crops and trees.

Deliverables:

1. Development of environmental-friendly methods of crop protection.
2. Genes/QTLs for resistance to pests/pathogens and other biotic factors.
3. Genes/QTLs controlling water- and nutrient-use efficiency.
4. Development of protocols of biological control.
5. Development of management techniques to improve resource-use efficiency and soil quality (e.g. water, nutrient, rhizosphere biota, etc.).

Goal three: Preserve and boost biodiversity

The intensification of agricultural practices in modern agriculture has led to the erosion of genetic diversity as well as to a reduction of wild areas. It has been estimated that more than 1/3 of the world plant species are affected by genetic erosion or even endangered (FAO source). In Europe, many forest and marshland areas have been converted into farmland over the centuries, and this process is continuing. These new scenarios require the development of tools to preserve, characterise and monitor biodiversity on farmland, in forests, as well as in the surrounding wild areas, also assessing *in situ* diversity for traits of adaptive significance. Additionally, the conspicuous and yet little exploited genetic variation present in available germplasm of wild relatives of major crops deserves serious attention: effective screenings for the presence of superior alleles and efficient transfer strategies, nowadays largely feasible, are expected to allow their successful exploitation in breeding.

All the major species related to the Mediterranean diet suffer severe damage from a number of pathogens. A deeper understanding of the dynamics of pathogen spread should help to devise better agricultural practices and help to protect biodiversity. Accessing to genome sequences of important pathogens is the first step in the analysis of the biodiversity of these pathogens. Of special interest is the access to virulence and pathogenicity genes which by mutation and recombination can lead to new host specificity. A better knowledge of the biodiversity of pests and pathogens and beneficial micro-organisms (including mycorrhizal and endophytic fungi and bacteria) is also needed to anticipate strategies of crop protection. Innovative metagenomics approaches like those allowed by high-throughput sequencing can be applied to profile the rhizosphere.

The protection strategies have to rely on the exploitation of the biodiversity of genetic resources for the improvement of crop tolerance to pests and pathogens. The pathogens that have the most serious economic impact on Italian crops and trees will be targeted for an in-depth analysis of their biodiversity and that existing in core collections of wild species related to the species of interest. Functional analysis of host-pathogen/pest interaction should combine transcriptome analysis, chemical mutagenesis, TILLING and RNAi approaches to identify the function of genes regulating the aggressiveness of each pathogen/pest. For trees, genomics know-how and toolkits are available and can be used first to describe the patterns of nucleotide variation at loci that govern variation in traits related to adaptation over a wide geographical area, with steep clines for the adaptive traits.

For the main species, mini-core collections capturing a large amount of the allelic variability within each species should be assembled and systematically analysed for linkage disequilibrium between haplotypes and distinctive phenotypic traits. This requires high-throughput genotyping and phenotyping. The genetic determinants of major traits will be further dissected through association mapping and classical QTL analysis. These approaches will lead to the identification of superior haplotypes which are exploitable for the release of elite varieties via marker-assisted breeding. Major QTLs can be cloned to identify the molecular basis of these traits hence paving the way to TILLING, EcoTILLING and/or cisgenic approaches. Other valuable approaches to more fully protect and exploit the biodiversity present in cultivated species are the creation of (i) *in vitro*- and cryo-banks of plant germplasm, (ii) libraries of introgression lines spanning the entire genome, or defined regions of specific interest, of the target species, (iii) advanced-back cross mapping populations, (iv) databases of local plant-symbiont associations, (v) exploitation of local ecotypes, and (vi) development of metagenomics libraries.

Research challenges:

1. Defining protocols for assessing biodiversity of beneficial insects, spontaneous plant species, mycorrhizal fungi, soil living micro-organisms based on DNA sequence inventories in order to monitor and compare the impacts of different agricultural and forest practices on agro-ecosystems.
2. Setting up protocols for the *ex situ* preservation of threatened plant and microbial biodiversity based on innovative technologies such as cryopreservation and slow growth storage.
3. Assemble and characterize mini-core collections and derived wild-to-crop introgressuion lines suitable for identifying genes/QTLs for target traits by association mapping.

Deliverables:

1. Improved knowledge of the available biodiversity.
2. Innovative strategies safeguarding biodiversity.
3. Improved knowledge of host-pathogen and host-symbiont interactions.
4. Mini-core collections for the main crops of local interest.
5. Improve crop biodiversity by introgressing traits from wild relatives.
6. Plant and microbial genetic resources in agriculture and forestry.

Goal four: Enhance the sustainability of the landscape

The term landscape refers to the way in which physical features of a land interact with living elements of flora and fauna, and human activities. In a plant context, we can identify very diverse situations where the remarkable semi-natural and cultivated regional landscapes of Italy are a valuable ecological resource to be protected and enriched further. In Italy, there is a thriving market for breeding flowers, bulbs, nursery shrubs, grasses and trees, particularly in Liguria and Tuscany.

Whilst intensive crop production management techniques will be adopted for some areas of high grade land, other lower grade land areas will be more suitable for conservation and recreational purposes. These measures will contribute to reduce rural depopulation due to global markets and reductions of subsidies to agriculture. For centuries, rural areas have been managed and modelled by local populations as cultural landscapes with a strong agricultural and forestry character. People living in such rural areas could be encouraged towards a more advanced forestry management. Trees form the foundation of multibillion Euro forest products industries, including the conversion of biomass to energy. There are more than 10 million forest owners in Europe who are dependent on the sustained management of forest trees to secure their livelihood. Despite their importance from both environmental and economic perspectives, little is know about the cellular mechanisms that underpin the growth and survival of trees. This is surprising, given that an understanding of these mechanisms will guide efforts aimed at ensuring the long-term maintenance of forest health, and the enhancement of forest productivity. For example, advanced forestry management may favour the production of edible ectomycorrhizal fungi (e.g. truffles, porcini), which represent an important income for some local Mediterranean communities.

In conclusion, the neglect status of rural marginal areas should be regarded as a result of recent societal changes, which relegated the agricultural dimension to the most favourable areas, triggering large-scale depopulation in marginal areas. A contribution to the rescue of soil degradation may derive by phytoremediation. Many plant species, in fact, have the potential of taking up and tolerating various kind of pollutants including agrochemicals and heavy metals, and may be used for cleaning up contaminated sites. Lastly, plant species naturally adapted to extreme environments can be introduced and/or re-introduced to preserve degradation of marginal areas exposed to soil erosion and desertification.

Research challenges:

1. Explore, catalogue and preserve indigenous biodiversity of plant communities and their rhizosphere.
2. Based on advances in modelling, to develop a deeper understanding of regional landscapes, products and services, for the creation, restoration and spatial organization of habitats.
3. Discovery of genes responsible for pollutant uptake and/or tolerance for local plant species transformation.

Deliverables:

1. Ornamental plants with novel attributes, collections of indigenous plants and practices to avoid the spread of alien invasive species.
2. Products and services to enhance natural environments.
3. Sustainable multipurpose landscape management.
4. Promoting innovative and sustainable land-use strategies to preserve cultural landscapes from abandonment.
5. Local plants able to decontaminate polluted land and to counteract desertification processes.

Challenge 4

Vibrant and competitive basic research

Basic research will play a pivotal role in the future activities specifically oriented to improve food production, sustainability of agriculture and production of raw materials and "smart" molecules in plants. New tools, platforms and paradigms derived from basic research contribute to the competitiveness of plant-based industries. The sequencing of the entire genome of the model plant *Arabidopsis thaliana* is an example of an overly important achievement of basic research in plant biology. Ever since, both basic and applied research in plant biology have operated within a new paradigm, boosting the development of systems biology and paving the way for a new understanding of plant functions. Italian scientists involved in Arabidopsis research, often in collaboration with European or other research groups worldwide, are currently deciphering the function of the genes of this model plant. Arabidopsis research has highlighted the importance of basic research and "omics" technologies for the progress of modern plant science. The knowledge we gained on the Arabidopsis system is helping the development of similar approaches on cultivated plant species.

Italy, with its long-standing tradition in basic plant research, should play an important role within this challenge. The Italian community of plant scientists, though small and poorly funded, has a good production of scientific literature. Intellectual property will be critical to secure healthy, nutritious and safe food, develop valuable "green" products, provide cheap, reliable and durable sources of bioenergy and biofuels, and build the human resources and infrastructure that are needed to enhance the competitiveness of European basic plant research in a rapidly changing world.

Meeting the needs of the scientific community while providing the infrastructure to effectively harness the potential of basic research relies on the following goals:

1. Genome sequences of crops and pathogens of particular interest for Italian agriculture.
2. Understanding the dynamics of transcripts, proteins, metabolites and relative interactions.
3. Proteomics and beyond: from protein sequence to fine structure/function relationships and their integration in the plant cell.
4. From gene to phenotype.
5. Systems biology and prediction of novel traits.
6. Building human resources, infrastructure and networking.

Goal one: Genome sequences of crops and pathogens of particular interest for Italian agriculture

Genome sequences represent the first level of basic knowledge for plant scientists. The recent development of plant science has been strongly stimulated by the knowledge of the Arabidopsis genome sequence and the public availability of all related information and post-genomic tools. Deciphering genome sequences of crop species has become more and more feasible and cost effective: important species such as rice, poplar, grapevine, sorghum and maize have also been sequenced. Genome sequences open up new perspectives for research to understand the differences between genotypes – both within a species and between phylogenetically related and even very distant species. In comparison to the animal community, so far the plant community has suffered from the paucity of genomes sequenced that prevents the adoption of comparative approaches to better understand the evolution and functions of genomes and genes. A push for the sequencing of new plant genomes will come from the new interest in crops for the production of energy. Italy has very few sequencing centres working on plant genomes and will therefore have to look for opportunities to take part in large international projects on the sequencing of new plants and try to gain a leadership in the so-called next generation sequencing technologies. Because the advent of the new sequencing technologies leads to a quantum increase in the amount of data produced, the simultaneous development of computational and bioinformatic capabilities and infrastructures becomes a must.

Goal two: Understanding the dynamics of transcripts, proteins, metabolites and relative interactions

Plant gene functions in relation to development, metabolic pathways and environmental stresses can only be understood when we analyse them at the transcript, proteome and metabolome level. It will be essential to perform these analysis in model species for which a large set of tools is already available. However, this kind of research must also be undertaken using crops that are important for Italian and European agriculture. One of the most challenging research questions is to understand how genes that regulate development, metabolic pathways and responses to stresses are controlled at the molecular level. Knowing how the key factors regulate plant processes will allow their optimisation for the improvement of agricultural products and to make their production more sustainable.

Goal three. Proteomics and beyond: from protein sequence to fine structure/function relationships and their integration in the plant cell

Ultimately, most biological processes are carried out by proteins. Therefore, we must increase our knowledge of how proteins work, interact with each other and other molecules and are activated and distributed within the cell, what regulates their turnover and how the protein contents of cell types and subcellular compartments change with development and environmental interactions. This will produce invaluable data to understand gene-phenotype relationships and for systems biology. High-throughput proteomics analysis of cell types and subcellular compartments, post-translational modifications and changes that occur during development and upon stress need to be integrated by detailed studies on the structure/function relationships of individual plant proteins and of multi-protein machineries. Elucidation of the mechanisms of subcellular compartment biogenesis and homeostasis is also fundamental to understand how metabolic pathways are integrated. For this goal, we will also need to develop new platforms for proteomics, protein three-dimensional analysis and fine morphological and dynamic analysis of subcellular structures.

Goal four: From gene to phenotype

In order to most efficiently and safely develop new crops to meet growing social needs, it is pivotal to uncover the functional significance of all the genes of relevant plant species within their cellular, organismal and evolutionary context. The recent technical advances in genome sequencing and "omics" approaches provide, for the first time, the tools for a comprehensive whole-system analysis of the genetic determinants of plant form and function. As Arabidopsis and rice are far ahead of all the other plant systems, challenge 4 will focus on these two species. Nevertheless, implicit objectives will be the transfer of technologies and information from model systems to crops, and to develop genetic, bioinformatics and "omics" tools suitable for the plant species most relevant for the Italian agriculture.

Goal five: Systems biology and prediction of novel traits

As scientists have developed the tools and technologies which allow them to delve deeper into the foundations of biological activity (genes, RNA, proteins and metabolites) they have learned that these components interact with each other in highly structured and complex ways. Systems biology seeks to understand these complex interactions, as these are the keys to understanding life. One application of systems biology will be that specific key regulatory genes can be identified in a highly complex network and changes in their function can be tested *in silico*, thus facilitating the identification of novel traits in crop plants.

Goal six: Building human resources, infrastructure and networking

Human resources, research infrastructures and networks are three crucial building blocks for the success of this Strategic Research Agenda. Training platforms need to be established that are very flexible in subject, capacity and timing to respond efficiently to the needs of scientists and students. Translating academic findings into benefits for European society, closer co-operation between academia and industry is required. Major investments and developments in bioinformatics will be required to allow effective storage, analysis, integration and mining of the functional data provided by the "omics" technologies. Additional key infrastructures with an appropriate critical mass in terms of personnel and equipment will also be necessary to guarantee access to biological and genetic resources, including access to well-developed bioinformatics and data mining capabilities. Accordingly, high-throughput phenotyping platforms will be required in order to select genotypes or alleles and/or genes that maximise agricultural output. Essential for genomics research is having access to high-throughput facilities duly equipped with instruments, robots and computers. Finally, mechanisms and opportunities to promote large scale, trans-European research collaborations need to be established to enable greater creativity and productivity in basic plant research.

Strategic Research Agenda of the Italian Technology Platform

Goal one: Genome sequences of crops and pathogens of particular interest for Italian agriculture

Italy is very rich in agricultural biodiversity, which could now be explored in genomic terms. Genomics allows us to compile inventories of natural variants within species or closely related species and local cultivars, providing information on new alleles with potentially interesting applications. Up to now, public funding on plant genomes sequencing projects in Italy has been scarce. However, genomic research is an absolute need for basic and applied plant research. Genome sequencing must be fuelled by sustained investment. Specialised centres for genome sequencing and bioinformatics will add to efficiency and cost-effectiveness and will facilitate Italian participation in large international sequencing projects. Central databases and stock centres will need to support the different genomics programmes. Plant species of economical relevance for Italy for which genomic projects are not yet in progress should be investigated. In the case of large genomes (e.g. wheat), investment in new sequencing strategies will be of fundamental importance. Plant pathogens cause significant yield losses and decrease in quality of the final products in agriculture. Major plant pathogens that are particularly important for Italian agriculture will be investigated. Acquiring a better knowledge of pathogens and plant-pathogen interactions will reduce the use of agro-chemicals to protect crops.

Research challenges:

1. Sequencing projects of species of national interest such as wheat, citrus, olive tree, etc. or plants important to basic science. The production of high-quality reference sequences should be a priority in this context in order to maximize their utility for the resequencing efforts needed for germplasm analysis.
2. Resequencing of germplasm within species to produce inventories of natural genetic variants and enable the identification of superior alleles.
3. Analysis of chromatin structure, DNA methylation, small RNAs, gene expression. Sequencing of complex genomes using new approaches that are alternative either to whole-genome shotgun or BAC-by-BAC approaches.
4. *De novo* sequencing, resequencing and bioinformatics of genomic sequences. Efforts will be concentrated in a limited number of specialized

centres that serve the national scientific community. The development of informatics infrastructures and capabilities will be a priority.

Deliverables:

1. Genomic sequences of plants and crops of interest to the Italian scientific community.
2. Inventories of genetic variants for major crops on selected regions of the genome or at the whole genome level.
3. Chromatin, DNA methylation, expression and small RNA maps for the genomes of the sequenced species.
4. New methods for the sequencing of complex genomes using next generation sequencing technologies.
5. National reference centres for genomic sequencing, resequencing and bioinformatics.

Goal two: Understanding the dynamics of transcripts, proteins, metabolites and relative interactions

Genome sequencing is the first step toward a deeper knowledge of complex organisms. The next step is to detect and measure the temporal and spatial levels of transcripts, proteins and metabolites in plants. Protein-protein and protein-DNA interactions and post-translational modifications should also be investigated (see Goal three). Platforms for transcriptomics, proteomics (see also Goal three) and metabolomics dedicated to model organisms like Arabidopsis and rice and to crops of major interest for Italian agriculture are required to adequately sustain these advanced studies. The integration between different disciplines will help producing and analyzing large experimental data sets (see Goal five).

Alongside with the completion of genome sequencing projects, it is becoming quite clear that to better understand the complexity of genome organization and to establish relationships with transcriptome and proteome composition, the study of the interactions of transcription factors (TF) and gene regulatory regions is of pivotal interest. This is even more necessary for plant genomes which appear to devote about 7-10% of their coding capacity to TF. Detection and functional analysis of gene regulatory elements can provide insights to better understand the development and adaptation of complex organisms, which is of basic interest to improve agronomically important traits in plants. This analysis is strictly related to advances in the genomic and proteomic approaches, having at the same time the potentiality to complement their results.

Research challenges:

1. Transcriptome, proteome (see also Goal three) and metabolome analysis on single or small groups of cells to study the function of genes that control plant development, metabolic pathways and stress responses.

2. Detection and analysis of gene regulatory elements, based either on robust and well-established techniques (genome walking - for agronomically important plants, whose genomes have not been sequenced yet; gene reporter analysis; EMSA) and on innovative approaches such as quantitative analysis of interactions of transcription factors with regulatory elements (by high throughput platforms based on microarray technology) and chromatin immunoprecipitation (ChIP) techniques. Massive identification of TFs is also a priority objective.
3. Identification of upstream and downstream loci that control development, metabolic pathways and stress response to dissect complex regulatory pathways.
4. Besides model species like Arabidopsis, rice and maize, new models will be identified as a starting point for new types of applications for the production of foods, biofuels and other direct benefits for the Italian agro-industry.

Deliverables:

1. New technologies to analyse protein and metabolite profiles at the single cell level.
2. Transcriptome, proteome and metabolome data in relation to plant developmental processes, metabolism and stress responses.
3. Knowledge of regulatory pathways that control development, metabolic pathways and stress responses in model species and important crop plants.
4. Development of new model species useful to study processes that have high priority for agriculture.

Goal three. Proteomics and beyond: from protein sequence to fine structure/function relationships and their integration in the plant cell

Proteomic studies will provide a direct assessment of the biochemical processes active within a given plant tissue. Post-translational modifications, often essential for function, are also detectable only by directly studying proteins. At the super-molecular level, the definition of multi-protein machineries and subcellular compartment proteomes will also be essential for a complete picture of molecular interactions. At the sub-molecular level, domains, subdomains and short unstructured amino acid sequences within a given gene product dictate quaternary structures, binding properties and catalytic activities, and form signals for subcellular localization as well as determinants for protein stability. Determining the three-dimensional conformation of proteins by crystallography and other techniques and defining the function of protein domains and signals by protein engineering followed by expression in vivo and in vitro, is the necessary integration of the "omics" studies. Italian plant biologists have a long-standing tradition in plant biochemistry and cell biology that needs to be supported and further developed to define the detailed structure/function relationships within the sequence of important proteins for plant development, reproduction, productivity and interactions with the environment as well as for the biogenesis and homeostasis of subcellular structures. The results obtained by this goal will also provide the necessary set of organized data for the development of goals four and five.

Research challenges:

1. The proteome of individual tissues (ideally of individual cells types) needs to be identified in relationship to plant development, reproduction and interaction with the environment.
2. The extent of post-translational modifications such as phosphorylation, glycosylation and lipid modification needs to be determined for each proteome.
3. For important individual proteins, the fine structure/function relationships must be determined by three-dimensional structural analysis and by *in vivo* and *in vitro* expression systems. Up-to-date platforms for studying protein structure will be essential.
4. The proteomes and the fine mechanisms of biogenesis and homeostasis of the different subcellular compartments must be defined. Platforms for the fine determination of protein localization and dynamics within the cell is fundamental for this goal.

Deliverables:

1. Qualitative and quantitative maps of the proteome of individual cell types and subcellular compartments and a picture of how they change with development and environmental constraints.
2. Quantitative and qualitative analysis of protein post-translational modifications at the level of individual cell type and in relationship to development and stress.
3. Determination of the three-dimensional structure and of sequence/function relationships for a number of important plant proteins.
4. New antibodies against important plant proteins.
5. Identification of signals and molecular machineries that regulate the biogenesiss of intracellular compartments and their interactions.

Goal four: From gene to phenotype

Long-term goal of basic research in plant biology is to provide information on how plants grow and respond to changes in their environment, what are the molecular bases of variation between and within species in the field. Genome sequencing and data generated by the “omics” tools (goals 1 and 2) will deliver candidate genes of particular interest for their role in regulating one or more aspects of plant development and physiology. The selected genes will be functionally analysed in vivo, either by using natural mutants or by applying a transgenic approach in which each gene is ectopically up- or down-regulated. To this end, automated platforms for high-throughput imaging will be established for both Arabidopsis and rice. The platforms will be then optimized for phenotyping selected crops relevant for Italian agriculture. Phenotyping platforms will also be exploited to survey the germplasm of the main crops that contribute to the Mediterranean diet (e.g. wheat, tomato, rice, etc.) and to select genotypes, QTLs, genes or alleles which maximize plant performance under optimal and/or stress conditions. Particular attention will be devoted to abiotic and biotic stresses known to represent major limitations for crops in the Italian environment. Collections of mutants suitable for TILLING will be developed to facilitate the identification of novel allelic variants of loci affecting major crop traits.

Research challenges:

1. Identification of candidate genes, controlling yield stability and quality, with focus on tolerance to cold, drought and salinity; response to pathogens (fungal, bacterial, viral, insect feeding), water- and nutrient-use efficiency (N, P, K), plant architecture and phenology.
2. Identification of enhancers and cell-specific promoters for the ectopic expression of target genes. Microarray expression analyses, reporter genes (i.e. GUS, GFP) and laser capture microdissection (LCM) experiments will be implemented to identify tissue- or cell-specific promoters, stress- or pathogen-inducible promoters, developmental stage-specific promoters.
3. Establishment of platforms for the functional analysis of the selected genes in model systems (i.e. Arabidopsis and rice), including: high-throughput gene cloning and transformation technologies for the ectopic expression of the selected genes and for promoter::reporter fusions analysis; automated non-destructive systems for in vivo large-scale phenotype analyses (e.g. image acquiring and elaboration systems).
4. Implementation of high-throughput phenotyping platforms for the identification of “elite” genotypes for the crop of interest, with superior performance under optimal and stress conditions.
5. Identification of QTLs, genes or alleles responsible for the best performances optimal and stress conditions.

Deliverables:

1. Novel genes controlling relevant agronomic traits, both in model plants and crops.
2. Novel plant promoters for the tissue/cell- or stage-specific expression of selected target genes in crops.
3. Selection of “elite” genotypes and cultivars, best fitted for the different Italian environments and agricultural systems.
4. Novel markers for molecular-assisted breeding of new cultivar with increased yield, enhanced quality and higher performance under abiotic and biotic stress conditions.

Goal five: Systems biology and prediction of novel traits

Systems biology is the study of an organism, viewed as an integrated and interacting network of genes, proteins and biochemical reactions. These interactions are ultimately responsible for form and functions of each organism. Systems biology will allow us to investigate how single molecular components (see goals 1 and 2) affect key processes in plant development, environmental interactions, metabolism and physiology. Interdisciplinarity between mathematical, chemical, physical, computational and biological sciences will be required. Ultimately, computer models should allow us to predict which genes need to be altered in order to obtain a desired trait in a specific environmental scenario. Such prediction can be experimentally tested using the phenotyping platforms (Goal three). The applications of such prediction to plant breeding and will ultimately allow us to improve plants by design. Due to the complexity of living organisms it is at this moment not feasible to perform systems biology studies at the level of an entire plant. Specific cells or organs will be chosen to restrict the amount of data to be analyzed.

Research challenges:

1. Generation of large sets of cell/organ specific “omics” data related to specific developmental, metabolic or stress events.
2. New computer programmes for the analysis of datasets.
3. Creation of a (virtual) Italian platform for the integration of datasets that have been generated by international research efforts.
4. Use systems biology analysis to improve plants by design.

Deliverables:

1. A systems biology platform as a key to more effectively unravel the complexity of plants and as a tool to improve plant traits for the agro-industry.
2. Specific datasets that consider RNA, protein and metabolite fluxes and stability within cells.
3. Identification of candidate genes to improve traits important for the agro-industry.

Goal six: Building human resources, infrastructure and networking

Human resources, research infrastructures and networks are three crucial building blocks for the success of this Technological Platform. This involves the training of researchers, state-of-the-art facilities for research and technology development in general, and strong networking at the national and international levels. Traditionally, as compared to most European countries, Italy is lagging behind in these aspects, also due to the fact that the overall investment in research is lower.

Training and mobility challenge. Recent trends, such as interdisciplinary science and emerging research fields create novel educational needs. In the field of plant biotechnology, genomics and proteomics, scientists mobility is crucial: scientists need to be able to move flexibly between disciplines, countries and between academia and companies.

Training platforms in plant science. Several training programmes exist throughout Italy. However, these are not adequately coordinated. Training platforms need to be established that are very flexible in subject, capacity and timing to respond efficiently to the needs of scientists and students. To achieve this, a database of experts and host organisations should be established, supported by a flexible funding scheme.

Scientist mobility programmes. A number of high-quality laboratories exist throughout Europe. Connecting Italian labs with these European labs in the fields of genomics, proteomics, bioinformatics, physiology and ecology will help integrating these disciplines. Additionally, the exchange between academia and industry needs urgent stimulation in order to encourage Italian scientists to translate research findings into tangible applications.

Deliverables. Training platforms in plant science for PhD students; exchange grants for a transition between academia and industry.

Research infrastructures challenge. Increasing and maintaining Italy's competitiveness in plant science will require an updated research infrastructure. This includes a close interaction among research groups that will deploy genomics and proteomics platforms with centres of high-throughput genomic research, genetic resource centres for the maintenance and distribution of genetic collections, high-throughput phenotyping centres able to handle thousands of plants and bio-computing centres that maintain large biological databases and develop tools for mining the data. Consequently, the implementation of a national research programme should address these infrastructure needs.

High-throughput "omics" infrastructures. Specialised centres for high-throughput genome sequencing, functional genomics (e.g. transcriptome, proteome and metabolome profiling), specialized molecular screening (e.g. TILLING platforms), structural biology, cell biology, and genetic engineering for validating gene function (e.g. gene silencing through VIGS, miRNA, etc.) and/or creating new cisgenic accessions with cloned genes/QTLs.

Genetic resource centres. Centres for the maintenance and distribution of the large collections of genetic stocks developed in genomics programmes.

Phenotyping centres. Centres specialised in high-throughput phenotyping under controlled conditions that can handle in a highly automated fashion the accurate phenotyping of the thousands of plants that are required for gene/QTL discovery through either linkage and/or association mapping and for the forward screening of mutant collections.

Bioinformatics and database infrastructure. Bioinformatics centres for data storage and curation, outfitted with state-of-the-art databases that allow flexible queries of data across genomics and proteomics platforms and plant species.

Deliverables. High-throughput and large-scale biology centres in plant genomics and proteomics; genetic resource centres for collection and distribution of diverse types of molecular and genetic resources; novel high-throughput plant phenotyping technologies; network of Italian bioinformatics and database centres for functional genomics data.

Networking challenge. The networking of Italy's plant biotechnology research needs to be strengthened at three different levels. At one level, the Italian scientific community needs to better network through the establishment of a virtual centre for plant science research. The second level involves better interaction between academia and industry with an emphasis on improved knowledge and technology transfer. These efforts in the field of plant research should be coordinated with those of other countries.

Virtual centre for plant science research. A virtual centre for plant science research could bring together the leading Italian groups in plant science within a single dynamic framework. It would aim to maximise the impact and visibility of plant science research in Italy. It would help attract the best senior researchers, young brains and financing, as well as promote the coordination of research. This centre could provide a database of research centres and capabilities, ongoing research activities and job openings in the field.

Transfer of knowledge between academia and industry*.* Academic research institutions in Italy are less connected to industry than other European countries. The lack of close interactions between academia and industry means that public investment in basic research is not generating optimal return and fails to stimulate appropriately industrial technological innovation. On the other hand, seed companies are often reluctant to invest appropriately in research partnerships with public institutions unless the return is immediate, which is often not the case scenario in genomics-based research. In Italy, there is a lack of commercial spin-offs that foster the collaboration between public and private stakeholders. An appropriate funding scheme would encourage this kind of entrepreneurship.

International co-operation*.* The Technology Platform could explore future opportunities for international collaborations, wherever possible both with developed and developing countries. Of particular interest would be large sequencing projects (such as wheat), functional genomics and proteomics projects on model species and the identification of international flagship projects, such as the engineering of plants for specific bio-based products.

Deliverables. Virtual centre for plant science; programmes for "transfer seminar" between academia and industry; public-private joint ventures between academic institutions and private companies; international collaborative projects for genome sequencing of model and crop species and functional genomics projects on model species.

Challenge 5

Consumer choice and governance

This challenge includes horizontal issues (of general interest) that are intimately interconnected with vertical (focussed) issues of the first three challenges. In addition, society's demand to be involved in the decision-making process, leading to the application of technology to every-day lives, would also reflect on the guidelines concerning the more advanced research, i.e. challenge four. Public and consumer involvement, ethical and legal aspects of potential technological innovations, financial and incentive mechanisms are here treated as separate items, but clearly have an impact and strongly influence the research activities specifically oriented toward food production, sustainability of agriculture and production of raw materials and 'smart' molecules in plants.

Challenge five needs to consider the actors in the production chain as well as consumers and related socio-economic issues. The Italian position here is similar to that of other countries in the EU but also has some particularities. From the producers' point of view, Italian agriculture has suffered in recent decades from lack of competitiveness. Alternative strategies based on high-quality production have proved to be successful ways to face such difficulties for some products, but are likely unable to respond to the global needs of all branches of the sector.

From the point of view of the consumer, and of the general public, positions have been largely driven by a lack of knowledge of the real advantages/disadvantages and benefits/risks of new technologies in plant breeding (e.g. genetic engineering), sometimes leading to uninformed and unilateral advocacy of the precautionary principle in its strictest terms. At the same time, social demand for specific foods or environmental features (e.g. reduction of pesticides use, saving water, healthier food, etc.) would benefit from the new technologies dealt within this technological platform.

The challenge here is to adequately support basic research at the national level while enabling it to contribute to society's goals in a participatory and consensual manner. Accordingly, the specific goals that will be explored under this challenge are:

1. Public and consumer involvement.
2. Ethical, safety, legal and financial environment.

Goal one: Public and consumer involvement

Public and consumer involvement is a key step in regaining the interest and trust of citizens, and plays a multiple role in the context of this challenge, as it fulfils numerous social functions:

1. Involvement of the public gives the opportunity to bridge the gap between the lay citizen and the scientific community with an eye to helping decision-makers take into account public concerns in relation to biotechnologies and scientific findings in this field.
2. Involvement of the public enables traditional knowledge and various kinds of 'local knowledge' to be expressed, debated and taken into account in the decision-making process.
3. Public participation provides the opportunity to investigate what interests, values and world views are part of the debate and to understand how they influence the positions of the various stakeholders.

In the case of food, consumer choice depends very much on cultural habits, ethical values and popular beliefs. In order to create successful strategies for sustainable, competitive and *socially acceptable* technologies, early involvement of the research on stakeholder attitudes and on adequate (within various social contexts) techniques of public involvement, is essential. This should be followed by the development of appropriate communication strategies enabling knowledge transfer among various social actors, reciprocal learning, negotiation and conflict resolution where value and interest contrasts are present. This is a particularly relevant and complex issue for Italy where consumer choice and producer attitudes are mostly oriented toward the promotion of quality and typicality, which is sometimes perceived as antithetical to innovation. In addition, Italy, like many other Southern countries, suffers from a deficit of public participation in the political process, hence providing additional rationale for undertaking actions aimed at addressing improvements in citizen involvement, for all of the above mentioned reasons.

Goal two: Ethics, safety, legal and financial environment

An ethical, safety, legal and financial environment capable of allowing science to improve quality of life and competitiveness is a major challenge for the EU, and particularly for Italy. This involves a transparent consideration of ethical issues, a rapidly adaptable legal environment, a clear consideration of incentives along the crop chain, and enhancement of public funding. Increased and more focused public funding at the national and regional levels is required to prevent Italy from further falling further behind its competitors. Furthermore, regional and local research programmes need to be harmonised and coordinated, so that current fragmentation and inevitable overlaps are minimized.

Goal one: Public and consumer involvement

Regaining the interest and trust of citizens in plant science is a key step for public and consumer involvement. This involves enhanced trust between the public and plant science communities, an improved perception of research and the scientific community, and improved public knowledge. Strategies in this field may involve three approaches: 1) communication, 2) public participation in decision making processes, 3) adoption of improved scientific tools for technological analysis and evaluation considering multiple points of view, including various stakeholders' interests and values. While the first and second points are directly addressed in the EU TP Strategic Agenda, the third appears to be underdeveloped.

Research challenges:

1. Evaluation of the impact of plant-related research activities on economic, social and environmental aspects of agriculture, the food chain and consumers.
2. Analysis of the contribution of new technologies and varieties on technical developments in agriculture and the food chain, and on their role in contributing to consumer welfare, economic growth and rural/regional development.
3. Development of methodologies and activities for effective stakeholder involvement, and communication strategies to bridge the research community with the stakeholders involved in the food chain, promote informed decisions and more socially acceptable technology development.

Deliverables:

1. Stakeholder attitudes (e.g. knowledge, values, interests, etc.) towards future technologies in agriculture, particularly in plant breeding.
2. Prospective studies on expected diffusion, rationale, cost/benefit analysis of prospective technologies from a social, economic and environmental point of view.
3. Events and networks aimed at information exchange and participatory decision-making in order to strengthen the connection between plant researchers and all relevant stakeholders.

Goal two: Ethical, safety, legal and financial environment

An ethical, safety, legal and financial environment capable of allowing science to improve quality of life and competitiveness is a major challenge for Italy and the EU. Ethical and regulatory issues, coexistence problems, and financial encouragement for investment are key nodes addressed. However, present strategies in the agro-food sector call for going beyond such issues and adopting a more holistic approach. Coordination and incentives throughout all product chains, including policy and market effects, as well as legal and technical support for quality and safety assurance are major issues to be dealt with. Policy coordination is an additional issue that requires attention. As one of its key objectives, the Plants for the Future vision paper identifies the provision of a wide choice of plant-related products (food, feed, non-food plant products, etc.). Perhaps the most obvious examples are foods produced by way of advanced agricultural practices, and those produced according to organic principles.

The TP programme must consider risk evaluation and management, an aspect that could be perceived differently by different stakeholders. In this framework, an important point to be considered is the risk emerging from <u>not</u> adopting innovative technologies. There is a tendency, especially given the manner in which the precautionary principle is applied to new innovative products, to ignore the evaluation of continuing with traditional conventional products, and/or practices compared with the innovative new products or processes. It is important to consider a comparison of the old with the new in this respect.

Such challenges are particularly difficult for such a diversified and fragile agricultural context as the Italian one. In Italy different farming strategies coexist, products and policies are strongly locally differentiated, cultural meanings are attached to many local productions, and institutions tend to adapt slowly compared with other areas of the world. Accordingly, interactions and overlapping with other TPs are very likely (e.g. Food for Life).

Research challenges:

1. An analysis of strategies and vertical relationships in the food chain, in particular, between input suppliers and farmers, as well as on intermediate and final markets, as related to food safety concerns and plant breeding technologies.
2. Further development of management instruments to support information sharing and reduce risk, including traceability in the agro-food chains and related effects on supply chain coordination, as well as an analysis of the interaction between public and private quality systems.
3. An analysis of the economic and legal aspects in order to improve the technical means to guarantee quality and safety of the food/feed chain supply.

4. Identification of improved organisational forms to guarantee competitiveness in a context of diversified agriculture, including coexistence of GM, conventional, organic and high quality productions.
5. Evaluation of the ethical and social welfare implications of different policy instruments to promote/regulate the use of new plant breeding “products”, including impacts on consumers, the environment and related externalities.
6. Establishment of creative public-private partnerships.
7. An analysis of social-context factors involved in the assessment, management and communication of food-related risks and, especially, risks related to biotechnologies.

Deliverables:

1. Descriptive analyses and improved knowledge of relevant decision mechanisms along the food chain as related to new plant breeding technologies.
2. Improved management tools for quality assurance, traceability and labelling which address the challenges brought about by new technologies.
3. Improved coordination mechanisms for private agents along the food chain aimed at guaranteeing food quality and safety to the consumer, as well as in feed production.
4. Improved legal/policy/organisational options to exploit potential benefits from new technologies while limiting risks and contributing to economic competitiveness and social welfare.
5. New public-private partnerships able to boost Italian competitiveness through the application of modern biotechnology and the release of improved cultivars.
6. Incentive mechanisms such as patenting and royalty systems able to ensure the economic valorisation of scientific results and to guarantee financial support for further research projects.
7. Definition of a model for the platform development aimed at ensuring the valorisation of research results. This implies the definition of an implementation path able to translate scientific results into business opportunities. This path will include the following actions: a) involvement and training of agriculture entrepreneurs; b) communication and involvement of public and financial institutions, industry associations, final market and the all distribution channel actors; c) cooperation among producers; d) definition of the product lines included in the agro-food supply, in order to ensure that the requirements of distribution chains and food companies in terms of quality and quantity are met; e) elaboration of marketing strategies specific to every product market. The implementation model must be national and subsequently translated into local and regional plans, depending on territorial specificities.

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