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Plant genetic resources for food and agriculture: roles and research priorities in the European Union

EASAC policy report 17

December 2011

ISBN: 978-3-8047-3017-5

This report can be found at
www.easac.eu

building science into EU policy

EASAC

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Cover image: Native maize varieties. (Photo: Keith Weller/US Department of Agriculture/Science Photo Library.)

Copy-edited and typeset in Frutiger by The Clyvedon Press Ltd, Cardiff, United Kingdom

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Preface

The world faces major challenges of population growth, climate change, increasing social and economic instability and a continuing failure to achieve food security. The challenge of achieving food security is made greater by the recognition that it must be done in ways that are sustainable, avoid continuing loss of biodiversity, address the adverse impact of climate change and take account of changing food intake patterns that, in the European Union (EU), are leading to a rapidly growing public health burden of diseases associated with over-consumption.

In the past decade, several academies of science in Europe have drawn attention to these difficult issues and to the role that the biosciences can play in enabling an innovative and resilient agriculture to contribute to resolving the multiple problems. In 2004, the European Academies Science Advisory Council (EASAC) emphasised some of the ways by which advances in genomics could provide a basis to develop more productive and environmentally sustainable crop systems: in essence a new era in plant breeding whereby the linkage of genes to traits allows more efficient and predictable crop breeding approaches. Recently, the Accademia Nazionale dei Lincei in Italy with the assistance of EASAC organised a survey and workshop to collect and analyse information on the current situation in the identification, conservation and use of plant genetic resources for food and agriculture across the EU. This work confirmed that there is much scientific excellence and a significant degree of commitment in many Member States and by the European institutions, but that there is also much more that can and should be done.

The present report uses the outputs from that expert analysis to discuss the opportunities and challenges that face the EU in capitalising on plant genetic resources and in addressing the shared problems. Our objective is to describe what is needed in coherent policy formulation at a time of rapid change. In compiling this report, EASAC received considerable support from Enrico Porceddu and Toby Hodgkin, who helped to lead the workshop and draft its outputs. We thank them and all who contributed to the workshop for their endeavours. We also thank our colleagues on the Council and on the Biosciences Steering Panel of EASAC for their commitment to this area and their guidance in delivering the key messages, and we thank our independent referees who reviewed the draft report.

In addition to our primary purpose of providing an account of the roles and research priorities associated with these plant genetic resources in the EU, EASAC publishes the present report as part of the foundation for future EASAC projects in food and agriculture – reinforcing the critical importance of plant sciences for tackling a broad range of strategic issues for the EU. In future EASAC work we intend to stimulate further discussion of some major opportunities and challenges inherent in the sustainable intensification of agriculture. We have not covered policy issues for genetically modified crops in the present report but this will be the subject of our next project and other future work may encompass the application of plant genetic resources for innovation in other industrial sectors such as biofuels, pharmaceuticals, vaccines and chemical feedstocks.

We trust that the present report will contribute to informing policy development and to stimulating further debate; we welcome discussion on any of the points we have raised and on matters that might be studied in future work.

Brian Heap (President of EASAC),
Volker ter Meulen (Chairman of the EASAC Biosciences Steering Panel)

Summary

Plant genetic resources for food and agriculture (PGRFA) include the traditional crop varieties and their wild relatives, modern cultivars, breeding lines and genetic stocks which provide food, feed for domestic animals, fibre, clothing, shelter, medicine and energy. They are part of the world's biological diversity and come under the provisions of the global Convention on Biological Diversity (CBD), but they have additional properties which require special recognition within the framework of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGFRA).

Why are they important now for the EU? Europe is considered relatively species-poor compared with other parts of the world, but its biodiversity has undergone complex interactions with human populations whose activity transformed the continent into a centre of diversity for cereals, legumes, fruits, vegetables, industrial crops, oil crops, forages, medicinal and aromatic plants. Although deriving from other parts of the world, these crops developed distinct properties through the selection skills of farmers and breeders. Agricultural developments over the past 60 years, increasingly within a common EU policy framework, have helped to ensure food security and safety for a growing population, a reasonable standard of living for farmers, and the modernisation and development of the agricultural industry. However, these achievements incurred costs that are unsustainable: for example, considerable areas of permanent grassland and orchards were transferred to crop production, leading to augmented release of nutrients from the soil; rapid increases in the area of some crops such as maize and wheat occurred at the expense of other traditionally important crops; and a near doubling of the irrigated land area has been associated with an increase in agricultural inputs. These developments have been associated with, or directly led to, a loss of plant genetic resources and diversity in European production systems. The Common Agricultural Policy (CAP) reform introduced environmental measures, such as large schemes of set-aside land, reintroduction of fallows and encouragement of extensive agriculture. However, that was not without negative consequences: neglected or abandoned land lost environmental value, being often occupied by invasive species or subject to soil erosion or other degradation.

The loss of plant genetic resources has serious consequences for food security. Underpinning the agricultural advances of the past 60 years has been the development of increasingly productive and better adapted crop cultivars. These have depended on the continuing availability and use of a wide diversity of plant genetic resources. Factors such as climate change, the need for more sustainable production systems, the emergence of new pests and diseases and the importance of improving food quality, are expected to require an increased input of a wider range of plant genetic resources than before. The maintenance and use of plant genetic resources will therefore be increasingly central to our continuing ability to create a sustainable and competitive European agriculture and to feeding the world.

EASAC advises that the conservation and use of plant genetic diversity should be an important concern in Europe. The European Commission and national governments have made significant efforts to tackle the challenges by establishing programmes of conservation, characterisation and documentation. Nonetheless, inadequacies in conservation efforts remain and further action is urgently needed, particularly with respect to neglected and underused crops and crop wild relatives. The development of more effective use strategies is equally important.

What should be the new vision? In the view of EASAC, there is great potential to capitalise on advances in the biosciences, including the use of molecular breeding, to develop agricultural systems based on sustainable intensification principles, offering safe, high-quality products, while protecting the environment, supplying diversified public goods, promoting growth and creation of jobs in rural areas and reinforcing the competitive ability of the EU agricultural sector. The EU has a legacy of excellence in plant sciences. There is a critical need to strengthen our understanding of biodiversity and ecosystem services while also doing much more to identify and use plant genetic resources for agriculture.

The present report draws on a workshop organised by the Italian Accademia Nazionale dei Lincei and EASAC that identified key priorities for research areas:

- clarifying fundamental aspects of plant biology – using diversity to understand genome organisation, gene function and plant evolution;
- improving conservation science – for example, using molecular methods to modernise conservation practice, such as reducing the number of duplicated samples, and developing indicators of diversity;
- mobilising diversity to enhance sustainable productivity increases – focusing on useful traits and interpreting phenotypic characteristics;
- deploying diversity in production systems – including the study of plant–micro-organism co-evolution, improving adapatability and resilience, increasing production, tolerance/resistance to stress, and nutritional value.

What are the implications for policy-makers? Success in tackling these research areas requires increased policy commitment to co-ordinated and sustained EU-wide programmes and improved collaboration between the relevant scientific disciplines (including genetics and genomics, plant sciences, ecology, social sciences). In addition there must be improved linkage between all the activities inherent in plant conservation, research and breeding and improved use of the scientific evidence to inform strategic development for agriculture and land use.

New global challenges are emerging and the EU is not immune. Climate change is expected to have a considerable impact on agriculture and food availability, with significant losses and gains that will vary for different crops and for different geographical regions. New crops and new cultivars have to be developed throughout Europe adapted to new environments and to particular abiotic or biotic stresses or new combinations of these. Adaptation to, and mitigation of, climate change will require a different kind of agriculture which combines higher levels of resilience with changed production practices, such as the cultivation of low methane-producing animal feedstock.

Maximising crop production has not been perceived in recent years by policy-makers as a priority for the EU. However, the EU is a net importer of food/feed and has an overdependence on a few crops. Pursuing the scientific priorities for plant genetic resources can help to address the issues for EU food security, sustainability, crop diversification and nutritional value, and offers opportunities for restoration of neglected and underused land and for the development of new crops or new crop uses, such as biofuels, biomaterials and chemical feedstocks.

EASAC concludes by emphasising that it is vital for policy-makers in the EU and at the Member State level to recognise the crucial contribution that plant genetic resources can make to tackling the EU societal challenges across a broad front and ensuring policies are in place to support their enhanced conservation and use. It is essential to align the policy tools available in CAP reform with the imperative for increased innovation in agriculture; to appreciate the enhanced significance of the biosciences-based agriculture sector in contributing to adaptation to climate change and to managing and promoting biodiversity; and to give greater prominence in the current process of setting EU research priorities for the period up to 2020 to the new scientific opportunities now coming within range. Wider international collaboration can also make an important contribution and EU countries should continue to work for this while bodies such as EASAC strengthen their international collaborative activities in relevant areas.

1 Introduction

1.1 The global context

Social, economic and environmental vulnerabilities are global issues in the present century (Fisher et al., 2002). Rapid population growth, poverty and hunger, poor health, low levels of education, gender inequality, fragile and hazardous environments, and the lack of access to resources and services all contribute to these vulnerabilities and create a world in which, against a background of climate change and economic globalisation, it becomes increasingly challenging to ensure that human populations have an acceptable level of socio-ecological resilience.

Recently, international food prices reached their highest level for 30 years, as result of, *inter alia*, a poor harvest in several major producing countries, decline in food stocks, high energy prices, production of biofuels, speculation on futures markets and lack of investment in the agricultural sector (World Bank, 2008). Prices of agricultural commodities remain volatile and in 2011 over 900 million people do not have access to their minimum food requirements. At the same time, a similar number suffer from obesity and other diseases associated with over-consumption.

Agriculture has historically been the foundation of social and economic progress in the developed world. In many developing countries, variability in the agriculture system, including trade and foreign-exchange earnings, aid and investments, is an important contributor to national economic vulnerability. Currently 65% of the world's workforce (86% of rural populations) is active in the agricultural system (World Bank, 2008), and agriculture will continue playing a major role in development. At the global level, the share of agriculture production in total gross domestic product (GDP) is around 29%, in contrast to 2–4% in most of the industrialised countries.

The growing demand for food for a global population that is expected to increase by up to three billion over the next decades (World Bank, 2008)[1], and the increasing preference for more highly refined grains and animal products including meat as result of higher income together with the desire for better financial returns, have stimulated both the expansion of arable land, encroaching into forested and prairie areas, and the adoption of intensive agricultural practices that are threatening natural resources. Many agricultural processes are not sustainable: the over-use or misuse of agrochemicals, irrigation water, fertilisers and other inputs, the increased use of mono-cropping, the adoption of more uniform varieties and the loss of crop rotation are contributing to soil salinity, soil and water pollution and the erosion of agricultural biodiversity. Climate change is a very considerable environmental threat likely to affect ecosystems and their production potential, the dynamics of pests and diseases, and water availability. Extreme events (drought, floods or hurricanes) can also destroy production (Fisher et al., 2002).

Several reports and policy documents, such as those prepared by the World Bank (2008), the International Assessment of Agricultural Science and Technology for Development (IAASTD; 2008), the Royal Society (2009) and the UK's Government Office of Science, London (2011), have highlighted these issues. Broadly speaking, the reports agree on the need for an increase in agricultural production based on sustainable principles and informed by a better understanding of the constraints and interactions of the many variables affecting performance. The diverse contributions that the biosciences can make to sustainable agriculture have been discussed in detail elsewhere (Pollock et al., 2008); sustainable agriculture will have to ensure higher, more stable and more eco-efficient production, more nutritious food and better quality final products while using less land, fewer chemicals and other inputs.

1.2 Connecting science and policy in the EU

Although the agricultural production problems may be worse in developing countries, Europe is not immune and faces major challenges. However, Europe can capitalise on a tradition of scientific excellence in its efforts to tackle the multiple societal issues relating to agriculture. The present report draws on a workshop (Appendix 1) and survey (Appendix 2) organised by the Accademia Nazionale dei Lincei to determine the current situation in the EU appertaining to the availability of PGRFA and future expectations for using these resources.

Our present report describes the contribution that PGRFA can make to meeting the shared global challenges while building a strong, sustainable European agricultural system. The report aims to identify and clarify what the policy-maker needs to know in developing science-based strategies. The following chapters describe progress made on conservation of PGRFA, propound more general usage of these resources and outline some of the research that needs to be undertaken by European institutions

[1] According to recent new projections from the United Nations, the current world population of approximately 7 billion may reach more than 10 billion by 2100 (2010 Revision of World Population Prospects, UN Department of Economic and Social Affairs, 3 May 2011; http://esa.un.org/unpd/wpp/Other-Information/Press_Release_WPP2010.pdf).

to ensure that PGRFA make their full contribution to sustainable, intensified production.

The analysis and conclusions are directed at policy-makers in the European institutions (the Commission, Parliament and Council of Ministers), in Member States, and in other advisory and decision-making bodies, for example the Food and Agriculture Organization of the United Nations (FAO). The present report continues a tradition of EASAC interest in these issues; relevant previous EASAC outputs include the following publications:

- *Genomics and crop plant science in Europe*, 2004 – describing the opportunities and challenges for using genomics research to support plant breeding;
- *A user's guide to biodiversity indicators*, 2005 – discussing the broader issues for measuring biodiversity;
- *Ecosystem services and biodiversity in Europe*, 2009 – characterising the benefits human populations derive from the workings of the natural world, including agriculture.

We believe that our present report is particularly timely in view of (1) the current discussions on CAP reform, (2) the implications and opportunities for responding to the impacts of climate change, (3) the ongoing challenges for managing biodiversity and (4) the need to identify priorities in research and innovation to be funded by the European Commission in the period up to 2020.

2 PGRFA: special properties and contribution to reducing vulnerabilities

2.1 Special properties of PGRFA

PGRFA is a collective desgnation that includes the traditional crop varieties, modern cultivars, breeding lines and genetic stocks that, taken together, contribute to providing food, pharmaceutical compounds and other chemicals for industrial purposes, feed for domestic animals, fibre, shelter and energy. PGRFA also include crop wild relatives. Because these resources have evolved in interaction with human needs and habits, they can be described as the part of biodiversity '*that nurtures people and that is nurtured by people*' (FAO, 1995).

PGRFA are part of the biological diversity and as such come under the provisions of the Convention on Biological Diversity (CBD, 1992). However, they have additional and particular properties (Box 1) which require special recognition (Bhatti, 2009).

ITPGRFA, which came into force in 2004 (see section 4.2 and Appendix 3), recognises the special characteristics listed in Box 1.

Box 1 Distinctive features of PGRFA

(1) PGRFA have a fundamental role in satisfying basic human needs, with particular reference to global food security and sustainable agriculture.

(2) Countries are largely dependent on PGRFA that have originated in other countries: this makes countries interdependent.

(3) Many PGRFA have developed over long periods of time, based on material originating from different regions; thus they are the product of the activity of many generations of people in many countries.

(4) They are embedded in indigenous knowledge and culture, which are an integral part of their management.

(5) For the majorityof PGRFA, human use is a fundamental condition for, rather than a threat to, their survival.

(6) The interaction between environment, genetic resources and management practices that occurs *in situ* within agro-ecosystems has been, and will continue to be, relevant to maintain a dynamic portfolio of agricultural biodiversity.

2.2 PGRFA contribution to reducing vulnerabilities

Better conservation and use of PGRFA can make a major contribution to improved sustainability, food security, economic development and poverty alleviation, as well as to the adaptation to climate change (FAO, 2010).

Sustainable Agriculture. Plant genetic resources are vital in addressing many of the most important agricultural challenges related to sustainability. Varieties that are pest and disease resistant and compete with weeds require fewer chemical applications; those that use water more efficiently produce higher yields under water stress; and varieties that use nitrogen more efficiently require less fertiliser input, with a concomitant saving in fossil fuel and reduction in water pollution. While varieties having many of these characteristics already exist, plant breeders have to develop and maintain a pipeline of new varieties to meet the challenges of new pests and diseases, changing production conditions and emerging societal needs. The genetic diversity of PGRFA underpins the whole process of producing new varieties. Research supporting breeding and the introduction of modern technologies to reach the breeding targets in a focused and faster manner provides knowledge on the genetic architecture of plant populations and complex characters, allowing new strategies to be devised for breeding varieties endowed with the characteristics required.

Food security exists when populations have physical and economic access to sufficient, safe and nutritious food to meet dietary needs and food preferences. Food security exists when all people have physical and economic access to sufficient, safe and nutritious food to meet dietary needs and food preferences, for an active and healthy life (FAO, 2010). PGRFA are the essential biological basis for producing more and better food for rural and urban consumers, enhancing farmers' incomes and lowering and/or stabilising food prices.

Agricultural production, and crop production in particular, must increase substantially in order to meet the rising food demand of the world population. According to FAO increases in food production of 70% will be needed by 2050 (Bruinsma, 2009). Because only 16% of the world's agricultural production enters international trade (albeit this will likely change as the food system evolves), much of the increase will have to occur in countries whose food demand has so far been supported by the developed countries of Europe and America.

A significant contribution is likely to be made by local varieties which, as well as providing the genetic diversity for modern plant breeding, still make an essential contribution to food security in many countries. They are well adapted to marginal production environments, fit in with local farming systems and meet local tastes and nutritional preferences. Local varieties of neglected and underused species provide a particularly important contribution. Although the area sown with these crops is relatively small, they often contribute essential nutrients (Padulosi et al., 2002), and are an important part of the social and cultural fabric of local societies (Frison, 2009).

Economic Development and Poverty. Agricultural production is a major source of income for more than half of the world's population. Its growth is, therefore, a vital component of development and poverty reduction in many regions of the world. Necessary actions to support this growth include the development of the food marketing sector based on appropriate varieties, the evolution of effective market chains and the use of PGRFA to ensure food products with the properties required for domestic and overseas markets. Diversification – requiring access to a wider range of varieties and crops – is a key strategy for wealth creation, as is the identification and supply of niche markets. Plants are also an important source of pharmaceutical products. The current production of medicinal crops, as well as their future improvement, is dependent on genetic diversity and the ability to identify the genes involved in the biosynthetic pathways for desired compounds. Expression of these genes in microbial cell systems may serve to reduce the risk of extinction of rare medicinal plants. Herbal medicines are highly lucrative: annual revenues in Western Europe reached US$5 billion in 2003–2004, in China sales totalled US$14 billion in 2005 and in Brazil herbal medicines generated revenues of US$160 million in 2007 (FAO, 2010).

Climate change. Prediction models indicate severe effects of climate change on agricultural productivity in many parts of the world, but with some regions having longer growing seasons and becoming more productive, if high-yielding varieties adapted to the new environmental conditions would be available. Changes in pest and disease patterns are likely and, indeed, they may be already accelerating, resulting in the need for new resistant or tolerant varieties. Less predictable weather patterns may also require the development of varieties endowed with greater phenotypic plasticity (its resilience and modifiability) and more adapted to a wider range of extreme and variable conditions. Lobell et al. (2008) have shown that there will be both significant losses and gains in world crop production with marked differences in different regions and further comprehensive analysis of global trends has recently been published (Lobell et al., 2011).

Recent work to develop scenarios up to 2050, taking account both of projected climate patterns and carbon dioxide fertilisation impacts, suggests that net crop yields in Europe may be relatively little affected by contrast with many other regions (Muller et al., 2010; see also section 7.3). However, a study of western and central Europe emphasised that policy-makers must take note that climate change is likely to increase yield variability and, hence, price variability (Trnka et al., 2011): agricultural policy will need to respond by encouraging diversification of production to increase crop resilience. New crop cultivars (and new crops) will be needed throughout Europe, adapted not only to particular abiotic or biotic stresses, but also to new combinations of stresses and to new environments in terms of day length regimes and seasonal temperature patterns. To inform this objective-setting, it is also important to develop more rigorous models in projecting likely change and the contingent uncertainties, to take account of the complexity of the crop–climate–soil interactions (Rotter et al., 2011).

Research in plant science. Plant genetic resources are important as the source material with which to understand plant biology (see following chapters). They are instrumental to exploring diverse areas such as: size variation in genomes; abundance and distribution of repetitive DNA across gene maps and chromosomes; polyploidy of crops and its frequency in the plant kingdom; existence and mapping of major quantitative trait loci (QTL) responsible for important crop traits; relationships between specific DNA sequences and phenotypes; adaptation strategies that contributed to plant success in a range of habitats; impact of species on the composition of communities; the evolutionary process and rate of evolution in plants, including the reconstruction of their past history; and the prediction of their responses to global change. It is important to understand, however, that the use of plant genetic resources to develop new breeding programmes can be a lengthy undertaking (Smolders, 2005) and there is need to share the lessons of best practice in promoting agricultural innovation (Fears, 2007).

3 PGRFA conservation and use

3.1 Introduction

Ever since their domestication, crop plants have accompanied human beings in their migrations, spreading across continents. Over the past 100 years, the movement of PGRFA has become more purposeful. Interest in the introduction of material for breeding purposes guided Nikolai Vavilov in his numerous exploration and collection missions, allowing him to identify the centres of diversity of cultivated plants (Vavilov, 1926). The availability and transfer of genetic resources, as well as their conservation, became an international concern in the 1960s, when the FAO established international collaborative activities for PGRFA aimed at ensuring their maintenance and use.

3.2 The state of PGRFA maintenance and use

The recent publication of the Second Report on the State of the World's Plant Genetic Resources (SOW2) (FAO, 2010) indicates four major trends in PGRFA management of particular relevance to European agriculture (Toledo, 2009), summarised in Box 2 and discussed in further detail in the following text.

Box 2 Current trends in PGRFA identification and use

- Expansion of on-farm management of traditional crop varieties.
- Continued expansion of *ex situ* collections, although backlogs in regeneration, together with verification and over-duplication, also continue to be of concern.
- Development of improved linkages between on-farm management of PGRFA and those involved in *ex situ* conservation, and between conservation and use.
- Growth in public awareness of the importance of crop diversity, especially of formerly neglected and underused species.

On-farm managed diversity. Small-scale farmers using a range of diverse traditional varieties continue to play a major role in agricultural production in the developing world. These varieties provide adaptability, stable (albeit low) yields and are suited to low input farming. Over the past years, there has been emerging interest in the on-farm management of traditional varieties as a contribution both to conservation and to agricultural development (reviewed in Jarvis et al., 2008, 2011).

Diversity in ex situ collections. The total number of accessions (individual plant material) conserved *ex situ* has now reached over seven million, although it is currently estimated that only 25–30% of them are distinct, bringing the number of unique accessions maintained around the world to around 2 million. Collections held at 13 international (Consultative Group on International centres Agricultural Research (CGIAR) and the Asian Vegetable Research and Development Centre (AVRDC)) and at 16 national collections account for a substantial proportion of total *ex situ* resources (some 600,000 unique accessions) and show a broad regional balance. The standard of conservation and regeneration of collections has advanced, although large regeneration backlogs are still present (GCDT, 2008). While the total number of accessions is large, neglected and underused species and crop wild relatives remain under-represented in gene banks. Crop wild relatives are also under-represented in *in situ* conservation programmes (see Chapter 8 for further discussion).

Links between conservation and use. Online information and increasing knowledge of the material in collections and of the genetics of important traits has undoubtedly improved the use of PGRFA in Europe. However, there are still many problems associated with insufficient resources for research on PGRFA, as well as unsatisfactory links between communities conserving PGRFA and those using them in breeding and other research programmes.

3.3 Genetic vulnerability and erosion

Genetic vulnerability has been described as the condition that results when a widely planted crop is uniformly susceptible to a pest, pathogen or environmental hazard as a result of its genetic constitution, thereby creating a potential for widespread crop losses. Genetic vulnerability continues to be a significant threat in certain crops and countries (e.g. hybrid rice in China based on a single male sterile source). A significant example of the impact of genetic vulnerability is the outbreak and continued spread of the Ug99 race of wheat stem rust, to which the large majority of existing varieties is susceptible (Pretorius et al., 2000). Maintaining diversity of crops and varieties in production systems helps to reduce vulnerability.
For major crops in Europe, it would now be possible to make available a sufficient diversity for use in production systems to limit the risk of vulnerability.

The steady loss of diversity because of genetic erosion (loss of individual genes or gene complexes; FAO, 2010) in production systems has been a major reason for deliberate conservation activities. The First Report on the State of the World's Plant Genetic Resources (SOW1; FAO, 1998) presented a picture of high levels of erosion and continuing loss of diversity. However, over the last ten years it has become clear that the situation is more complex (FAO, 2010) and that rapid erosion is most commonly associated with the transition from a dependence on traditional varieties to one in which modern cultivars predominate. In Europe, genetic erosion associated with the introduction of deliberately bred cultivars has been significant for many crops. However, in instances where traditional varieties have continued to be grown, or where the commercially bred varieties have been present in the production system for the past 60 years (as in the case of wheat), levels of erosion have been much lower.

The assessment of levels of genetic vulnerability and genetic erosion is important to inform the development of agricultural production strategies, of resource allocation and decision-making. Therefore there is a growing interest in the development of appropriate indicators to guide policy-makers on these issues.

3.4 Interdependence

Most countries are heavily dependent on PGRFA derived from other countries in support of their food and agriculture production. European agriculture depends on wheat and barley from the Middle East, potatoes from the Andes, maize from the Americas and many fruit and vegetable species from around the world (see also Chapter 5). Southern Africa is more than 90% dependent on 'outside' crops. Manioc – originating in South America – is a major food source for more than 200 million people in 31 African countries. The extensive cattle pastures of Latin America depend largely on African grasses. Lucerne (*Medicago sativa*) from south-western Asia is now cultivated around the globe on about 80 million hectares. The interdependence of countries on plant genetic resources is relatively well documented, based on records of international pedigrees of cultivars and international movements of PGFRA at the service of agricultural research, training, and plant breeding (Frison and Halewood, 2006).

At the global and regional levels, a major consequence of interdependence is the need for the international exchange of germplasm (collection of genetic resources for the organism); but this has become more complex and difficult over recent years. Uncertainty about legal issues is a significant factor hindering international, and even national, germplasm exchange. The CBD general principles do not inspire clear and efficient procedures for accessing PGRFA, thereby hampering the collection and cross-boundary movement of genetic resources. These problems were among the key factors that led to the adoption of the ITPGRFA (see Chapter 4).

3.5 Constraints in current and future use

The improved use of PGRFA is a major goal in efforts to improve productivity, sustainability and global food security. Some 40,000 samples are distributed every year to breeding and other research institutions by the gene banks of the International Agricultural Research Centres (IARCs) and more than half of these are from traditional varieties. Public and private sectors, both in developed and developing countries, benefit from this distribution. However, major constraints remain, particularly with respect to characterisation and evaluation of gene bank holdings, availability of plant breeders, pre-breeding capacity[2] and improvement of minor crops.

The use of PGRFA presupposes adequate characterisation and evaluation of accessions and the capacity to generate and manage the resulting data, to enable plant scientists to select germplasm efficiently, avoiding the need to repeat screenings. The lack of availability of such data represents one of the most serious obstacles to the use of plant genetic resources collections (von Bothmer, 2009). Molecular characterisation of germplasm has now become more widespread across regions and crops and it is likely that such characterisation will become increasingly important to users, as sequencing methods improve and costs are reduced.

Success in plant breeding, whether through traditional selection or using the most recent molecular techniques, depends on the availability of genetic diversity and the ability of breeders to use diversity and assemble genes in new varieties. Recognising the need and relevance of new varieties, most countries support public and/or private plant breeding activities but significant limitations persist. Breeding programmes are in some cases decreasing in Europe and North America, particularly in the public sector (High Level Panel of Experts (HLPE), 2011). In addition, a lack of resources for field trials and for a full use of molecular methods often limits the exploitation of the potential provided by modern biology.

The resources available for variety improvement are usually concentrated on major crops, while minor crops often attract little or no resources. Therefore, although high profile problems (such as Ug99 wheat rust) may attract international efforts (the Borlaug Global Rust Initiative), other significant problems are effectively ignored. Plant breeding is, by its nature, a long-term investment and the use of PGRFA requires a continuing stable investment to achieve due returns. This is particularly the case when breeding for complex traits, such as drought or cold tolerance (Karamanos, 2009).

Pre-breeding[2] is an important adjunct to plant breeding, as a way to broaden the genetic base of crops and to

[2] Pre-breeding refers to the cycles of crossing and back-crossing needed to detect, map and select useful traits from wild relatives or other non-adapted materials before normal breeding, aimed at enriching genetic diversity in the breeding pool and transferring useful genes to material more closely suited to crop production.

introduce new traits from non-adapted populations and wild relatives, especially for disease resistance and the complex traits, such as abiotic stresses and yield potential. Pre-breeding occupies a unique and often crucial step between conservation and use of genetic resources. With declining levels of public investment, a significant gap in pre-breeding capacity has appeared in several European countries. Filling this gap would benefit from a collective EU effort in the public sector, which would also help to train the next generation of plant breeders (Royal Society, 2009).

Farmers participate in plant breeding programmes in many regions as part of PGRFA management strategies and to develop more adapted varieties. Farmers understand the yield limitations of their own crops, and their involvement has obvious advantages. Some institutions are exploiting this knowledge but in many cases farmer involvement has largely remained limited to priority setting and selection among finished crop cultivars. The development of sufficient numbers of adequately trained personnel, operating in the field and mastering advanced methods, including molecular biology and information science, remains a major priority for the better use of PGRFA. As with other constraints, improved international collaboration could reduce training costs and unnecessary duplication of investments. The use of regional centres of excellence has been suggested (Fulton, 2008). A further major constraint remains the lack of fully effective links between basic researchers, breeders, gene bank curators, seed producers and farmers; the lack of effective mechanisms to support collaboration limit and delay the use of germplasm resources in crop breeding both in developed and developing countries.

4 Access to plant genetic resources and benefits sharing

4.1 Introduction

As previously described, countries are interdependent on each other for plant genetic resources, and in order to achieve food security they need access to PGRFA originating from different countries across the world. During the 1960s, countries started collecting at home and abroad as much diversity as possible and assembling it in *ex situ* gene banks and experimental orchards, according to the principle that plant genetic resources were a heritage of mankind and therefore should be preserved and made available in the future without restriction. However, during the 1970s some governments in developing countries started claiming ownership of their genetic resources. At the same time, industrialised countries developed the International Convention for the Protection of New Varieties of Plants, as a measure for granting Intellectual Property Rights over new crop varieties. The attempt to convince developing countries to adopt protection of plant varieties and to pay royalties for varieties deriving from their genetic material promoted international tension. Protection of plant varieties derives from the interest of private breeders in protecting their intellectual property (the new variety) in return for their investment. Farmers have traditionally replanted, exchanged or sold harvested seeds and these practices, if applied to modern varieties, would prevent breeders from recouping, through repeat seed sales, the investment made in improving varieties. Conversely, patents impose restrictions on farmers' ability to sell and/or exchange harvested seeds.

To address these issues, the 1983 FAO Conference adopted an International Undertaking on Plant Genetic Resources (IU), aimed at ensuring that plant genetic resources were freely available for replanting in the same farm and for plant breeding and other scientific purposes. However, several countries indicated that they would not support this approach, because although the IU had provisions for rewarding the contribution of plant breeders it did not recognise the contribution provided by farmers in selecting and conserving these resources. Thus the FAO Conference in its 1989 meeting introduced the concept of Farmers' Rights and in its 1991 meeting established the International Fund to implement them.

Introduced in 1992, the CBD provided a comprehensive framework by which states have the authority to regulate access to genetic resources, but are committed to promoting conditions to facilitate access to them; at the same time, countries where genetic resources are used must share any benefits arising from their use with donor countries. This approach, which was essentially bilateral, involving negotiations between parties for each single exchange, proved problematic for farmers and breeders, and subsequent negotiations produced ITPGRFA.

4.2 ITPGRFA

The ITPGRFA, which was adopted by the FAO Conference in 2001 and came into force in 2004, draws together features of the IU and the CBD and establishes a Multilateral System of Access and Benefit Sharing for crop species important for sustainable agriculture and food security. In fact, it recognises that these are indispensable materials for crop improvement and that many countries depend on genetic resources originating elsewhere. It also recognises the contribution of farmers in conserving, improving and making available these resources.
The main principles and elements of the ITPGRFA are discussed further in Appendix 3.

The ITPGRFA has now been ratified by over 120 countries and activities to support its implementation have begun in many countries. Significant funding has been mobilised to support priority activities identified by the Treaty's Governing Body. These activities include capacity building, information management, *in situ* conservation, addressing the consequences of climate change and complementing the actions initiated by the Global Crop Diversity Trust in support of the Treaty's *ex situ* conservation objectives. A key issue that faces countries today, inluding Member States of the EU, is the need to mobilise additional resources to implement fully the terms of the Treaty and the activities which they, as signatories, have endorsed.

5. Europe and its agriculture

5.1 Introduction

The pressures described in the previous chapters are global and the EU is not immune. Europe faces a time of transformation and significant challenges, as indicated in EUROPE 2020 (European Commission, 2010). The financial and food crises of 2008 and 2009 have undermined achievements from years of economic growth and social progress, and exposed the structural weakness in the EU economy. Although surmounting the current economic crisis is the immediate priority, avoiding a return to the previous situation is also a major challenge. Even before recent events, the EU was not advancing at the pace of the rest of the world in many respects: average growth rate was lower than its main economic partners and competitors, largely because of a productivity gap, reflecting differences in business structures, lower levels of investment in R&D and an apparent reluctance to embrace innovation.

EUROPE 2020 emphasises that, to improve the competitive ability and create new jobs, Europe needs a greater capacity for research, development and innovation across all sectors of the economy and an increased efficiency in resource use. EUROPE 2020 specifies the need to complete the European Research Area, with a strategic research agenda focused on key challenges, in particular energy security; climate change and resource efficiency; environmentally friendly production methods and land management; prevention of environmental degradation, biodiversity loss and unsustainable use of resources.

5.2 Evolution of EU agricultural policy and its effects

The Common Agricultural Policy (CAP) has existed for more than 40 years as one of the most important pan-European policies, aiming to ensure food security and safety, to provide a reasonable standard of living for farmers, while allowing the agriculture industry to modernise and develop, and farming to continue in all regions of the EU. However, the CAP has been controversial and is likely to continue to be so. It attracts some criticism for distorting markets and, currently, Member States vary in their views on the path to CAP reform. The existence of a European agricultural policy which guaranteed the prices of agricultural products over decades has contributed to the intensification and specialisation of agricultural production. The results have been positive for yield, production and farmers' income and negative for environment, landscape and biodiversity. The consequences relevant to both PGRFA use and the environment are described in Box 3.

Box 3 Some consequences of CAP for European agriculture

- The transfer of permanent grassland to crop production (particularly between 1975 and 1995), which posed environmental problems in the short to medium term, including nutrient release. The area devoted to permanent crops and orchards was reduced, especially in the EU's northern Member States.
- Changes in the distribution of crops, including a rapid increase in the production of cereals with a shift from secondary cereals (barley, oats, rye) towards common wheat and maize. Changes in patterns and increases in quantity of the latter were particularly noteworthy. There was also rapid spread of industrial crops (rape, sunflower, soya).
- The area of irrigable land increased considerably, often accompanied by increases in other inputs, creating a completely different agro-ecosystem.
- Traditional European mixed farming and Mediterranean agriculture were replaced by specialised farms where crops, including fodder, were sold outside the holding.
- New crops, including silage maize, expanded land use. Sunflower, soya, maize and lucerne advanced northwards whereas rape was concentrated in continental areas.
- Farmers consolidated areas of land, leading to a simplification of the land cover structure, favouring open fields with loss of hedges, slopes and spinneys. This contributed to an increase in productivity but disturbed the normal biological flows of fauna and flora and induced migration or disappearance of species.

To counteract the emerging negative impacts, in the early 1990s, CAP reform reduced price support for the production of cereals, oilseed and protein crops. European cereal production fell by about 10%, but common wheat remained dominant, with a virtually unchanged acreage. However, stocks fell sharply, with greater amounts of the now more competitive domestic production being used for animal feeding. The most recent developments in CAP and the resulting expectations are described in Chapter 7.

5.3 The quality of habitats for biodiversity

Widespread set-aside had a new impact on the environment: forest areas increased, fallow land was re-introduced where it had been lost in the intensification process, but the change did not increase the quality of habitats, particularly in arid zones. Land which was neglected or abandoned lost environmental value; the absence of management led to a loss of biodiversity, with occupation by invasive species, erosion or other negative consequences (for example in the Mediterranean region, Garcia-Ruiz and Lane-Renault, 2011). Generally speaking, the 1992 reform of the CAP was a major but insufficient step towards a better integration of environmental demand and sustainability. In the subsequent CAP reform (Agenda 2000, 1996), the European Commission enhanced the role of ecology in agricultural activities and introduced a more structured and consistent policy of agricultural aid and environmental protection. The intention was to go beyond good agricultural practices and promote activities, in particular, reducing inputs, increasing agro-biodiversity, leaving field boundaries uncultivated, creating ponds or other features, planting trees and hedges. The goal was for farmers to observe a minimum level of environmental practice; any additional environmental service, beyond the basic level of good agricultural guidelines and respect for environmental law, would be paid for by society through the agro-environmental programmes. Thus, agro-environmental measures were reinforced and formed a compulsory part of rural policy programmes.

5.4 European agriculture: future prospects

According to the responses obtained in a Eurobarometer survey[3], society expects a CAP that promotes sustainable agriculture, offering safe quality products, while protecting the environment; it should support the multifunctional role of farmers as suppliers of public goods to society, promote the growth and creation of jobs in rural areas and reinforce a competitive ability of the agricultural sector (see Chapter 7 for further discussion).

Within the EU-27 agriculture and forestry occupy 47% and 31% of the territory, respectively; 68% of the agricultural area is used for arable crops, 25% for permanent grassland and 7% for permanent crops (EU Agriculture and Rural Development, 2010). Europe is considered to be relatively species-poor compared with equivalent regions in Asia and America. The largest number of plant and animal species in Europe are found in the Mediterranean basin, which is also one of the 33 'world biodiversity hot-spots' (Mittermeier et al., 2005). But Europe's biodiversity has historically been embedded in a rural environment, with complex interactions between populations in open habitats and a dynamic landscape, and this complexity has to be reflected in any effective conservation programme. The EU Common Catalogues of varieties of agricultural and horticultural plant species contain 18,000 and 17,000 varieties respectively, including woody plants for forestation and varieties of vine and fruit plants (Vinceti, 2009). The region is an important source of wild plants closely related to crop plants.

Nearly 55% of the population of the EU-27 live in rural areas covering more than 90% of the territory which generates 48% of the gross value added (GVA) and provides 56% of the employment (EC Agriculture and Rural development, 2010). The rural landscape thus remains central to European wealth generation and the well-being of its population. However, rural areas tend to lag behind in several socio-economic indicators and rural development is vitally important. Farming and forestry are the main land uses and play an important role: they are at the basis of a strong social fabric, they manage natural resources and landscape and they determine economic viability of the concerned regions (European Commission, 2010). Consumers are showing an increasing interest in the qualities of food products and the EU authorities are seeking a major role in enhancing and safeguarding these high quality attributes, for example via measures to enhance food safety and hygiene and clear labelling, regulations pertaining to pesticide residues and additives in food.

Europe is a major player in the world's agricultural markets: the EU has become the second largest exporter of many foodstuffs, worth €76 billion annually between 2007 and 2009. But the EU is also the largest importer of agricultural products in the world, valued at €81 billion annually between 2007 and 2009, and the EU's net export position has declined in every single sector since 1990. Can intensification of sustainable agriculture, capable of exploiting environmental and biological diversity, reverse this historical decline?

Climate change is bringing new issues, although its effects are uncertain and diverse, as noted previously. Current differences in crop productivity between northern and southern Europe are likely to increase under climate change. Exceeding crop-specific high temperature thresholds may result in a significantly higher risk of crop failure in southern Europe, while northern Europe may be able to grow a wider range of crops than is currently possible, because of warmer and longer growing seasons. Adaptive strategies, such as changing crop and crop varieties and altering sowing dates, will be needed to alleviate yield losses.

[3] Europeans, Agriculture and the Common Agricultural Policy, March 2010; http://ec.europa.eu/public_opinion/archives/ebs_336_en.pdf.

6 PGRFA in Europe

6.1 Introduction

Europe hosts centres of diversity for cereals, legumes, fruits, vegetables, industrial and oil crops, forages, medicinal and aromatic plants. However, most of these crops actually originated in other parts of the world and, in this sense, Europe has a significant dependence for its food security on non- indigenous crops. This dependence varies from 64 to 69% for Greece to some 90 to 99% for countries such as Finland, Norway, Poland, Romania, Sweden and the United Kingdom (Palacios, 1998). Over the centuries, these crops have developed distinct properties adapted to the different production environments of different parts of Europe through the selection skills of farmers and breeders.

The replacement of landraces (local varieties of domesticated plant species developed mainly by natural processes of adaptation) by high-yielding varieties since the beginning of 19th century, together with other developments of agriculture in EU Member States such as the establishment of large farms in Eastern Europe, has accelerated the erosion of genetic variation in the cultivated material. The extent of this erosion has not yet been fully considered in the recent efforts by policy-makers to address environmental issues. Today, the survival and maintenance of plant genetic diversity is a primary concern in Europe, where specific countries have taken steps to fulfil their responsibility for the conservation of plant genetic resources, both within the region and globally. About 500 bodies in Europe have seed storage facilities, as well as field gene banks, which maintain 2 million *ex situ* accessions (see Chapter 3). Activities are performed mainly by national institutions, under the co-ordination of several co-operative programmes. Several important research projects are financed or co-financed by the EU Commission. Some major examples are described in the following sections and in Appendices 4 and 5 to illustrate the strong scientifc legacy in this area that can be used to address the new opportunities coming within range.

6.2 Co-ordination activities

The ECPGR. A series of consultative missions and discussions, which took place in the 1970s, with the involvement of FAO, International Board for Plant Genetic Resources (IBPGR), EUCARPIA and the United Nations Development Program (UNDP) European office established a framework for collaborative development of PGRFA conservation in Europe. The programme European Cooperative Programme for Genetic Resources (ECPGR), formerly European Cooperative Programme/ Genetic Resources (ECP/GR), aims to contribute '*to the development of agriculture in the member countries by the more effective use of PGR, which are well conserved and accessible, and to further the activities of national and sub-regional institutions for PGR in Europe, by strengthening cooperation between such institutions*'. The programme underwent a series of three-year phases, during which the number of participating countries and institutions[4] increased from the initial 22 to the present 42, organised in 20 working groups[5] and nine crop and thematic networks[6].

The Programme is funded by the member countries with contributions based on the UN scale of assessment; the budget is dedicated to co-ordination and Network operations, whereas agreed activities are performed by institutions with their own resources. Activities are overseen by a Steering Committee made up of National Coordinators having a Secretariat at Bioversity International, Rome, Italy. ECPGR is used as a platform to facilitate the implementation of the Global Plan of Action for the European region as part of the FAO Global System on Plant Genetic Resources. It also interacts with other bodies, programmes or collaborative projects addressing issues of plant genetic resources, such as the Global Crop Diversity Trust, the Secretariat of the ITPGRFA (Appendix 3), SEEDNet and the Genetic Resources Programme of the EU. The current objectives of the Programme are detailed in Box 4, followed by a description of some of its principal activities.

EPGRIS – EURISCO. The final output of the project 'European Plant Genetic Resources Information Infra-Structure, EPGRIS', co-ordinated by the Centre for Genetic Resources, The Netherlands, and financed by the European Commission, was the European Search Catalogue – EURISCO – which currently contains passport data on more than 1 million samples of crop diversity representing 5,393 genera and 34,473 species from 40 countries, more than half of the *ex situ* accessions maintained in Europe and roughly 19% of total worldwide holdings. The Catalogue, which was developed and frequently updated by the National

[4] ECPGR member countries are the following: Albania, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, Lithuania, Macedonia (FYR), Malta, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation. Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom.
[5] ECPGR working groups: *Allium*, *Avena*, Barley, *Beta*, *Brassica*, *Cucurbis*, Fibre crops (Flax and Hemp), Forages, Grain legumes, Leafy vegetables, *Malus/Pyrus*, Medicinal and Aromatic plants, Potato, *Prunus*, Solanaceae, Umbellifer crops, *Vitis*, Wheat.
[6] ECPGR thematic networks: Cereals, Forages, Fruit, Oil and Protein crops, Sugar, Starch and Fibre crops, Documentation and Information, In situ on-farm conservation, Inter-regional cooperation.

Box 4 ECPGR objectives for Phase VIII (2009–2013)

- To facilitate the long-term *in situ* and *ex situ* conservation of plant genetic resources in Europe.
- To facilitate the increased use of plant genetic resources in Europe.
- To strengthen links between all plant genetic resources programmes in Europe and promote the integration of countries that are not members of ECPGR.
- To encourage co-operation between all stakeholders, including the development of joint project proposals to be submitted to funding agencies.
- To encourage the sharing of conservation reponisbilities for PGRFA in Europe.
- To increase awareness at all levels of the importance of PGRFA activities including their conservation and sustainable use.
- To seek collaboration with other relevant regional and global initiatives.

Box 5 Expected benefits from the national and collaborative European Gene Bank System

- Improved collaboration among European countries and a stronger, unified system.
- Cost-efficient conservation activities.
- Reduced redundancy in European collections.
- Improvement of quality standards across Europe.
- More effective regeneration.
- Facilitated access to all AEGIS germplasm.
- Improved security of germplasm through formal commitment and duplication for safety.
- Improved linkages of germplasm between *ex situ* and *in situ* conservation as well as linkages with users.
- Improved sharing of knowledge and information.

Inventories of PGR, is being maintained by Bioversity International, on behalf of the ECPGR Secretariat.

AEGIS. ECPGR has resolved to create A European Genebank Integrated System (AEGIS) for PGFRA, aimed at conserving the genetically unique and important accessions for Europe and making them available for breeding and research. AEGIS allows all germplasm accessions and the related information to be available and accessible to users. *Ex situ* conservation of germplasm is performed according to common agreed quality standards, independently of where the germplasm is physically located, and in such a way as to facilitate close linkages with *in situ* conservation. The benefits of establishing a rational and collaborative European genebank system are specified in Box 5.

EUFORGEN (European Forest Genetic Resources). This is a collaborative programme among European countries[7] that promotes the conservation and sustainable use of forest genetic resources, by developing science-based strategies, methods and recommendations for policy-makers and managers to improve the management of genetic resources of forest trees in Europe. Its activities are funded by participating countries and performed through working groups and networks; the Steering Committee is composed of National Coordinators from member countries and it has the overall responsibility for the Programme; the Secretariat is hosted by Bioversity International. In the first three phases the programme has gathered information on the status of genetic resources, research activities, methods, legislation, constraints in the participating countries and their needs and priorities. During phase three the implications of climate change on forest reproductive material were analysed and a closer integration of genetic resources conservation into practical forest management and national forest programmes was promoted.

6.3 Field activities

The Second Report on the State of the World's Plant Genetic Resources (SOW2) (FAO, 2010) is a good source of information on the plant genetic resources activities in Europe. The following paragraphs summarise the current situation; opportunities and challenges are further discussed in subsequent chapters.

[7] EUFORGEN participating countries are the following: Albania, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Moldova, Montenegro, The Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, the FYR of Macedonia, Turkey, Ukraine, United Kingdom.

Collection and conservation. The approximately 500 gene banks and other institutes in Europe, having storage facilities as well as field gene banks, maintain 2 million *ex situ* accessions, representing a wide range of origins. The situation is rather diverse among Member States: thus, whereas more than 75% of germplasm holdings stored in Greece, Romania, Portugal, Spain, and in the Nordic Gene Bank (NordGen) are indigenous, the percentage of indigenous accessions in other gene banks, such as those in Bulgaria, Germany, the Netherlands, and the Czech Republic varies between 14 and 20%. Austria, France, Hungary, Italy, Poland and Ukraine also conserve more foreign than native germplasm. Many accessions are duplications, whereas landraces and crop wild relatives of the Mediterranean, the Balkans, the Carpathians and the Caucasus are not adequately represented, in spite of the collecting activities recently performed by Hungary, Romania, Poland, Slovakia and Portugal. Some countries, such as Belgium, Germany, and Poland, maintain cryopreservation facilities; virtually all countries conserve some germplasm *in vitro*.Viability testing is performed regularly in most countries, but the level to which viability is allowed to fall before regeneration varies between 50% in Nordic countries and 80–85% in Poland.

Most countries have their collections safely duplicated in centralised collections on a crop-by-crop basis, whereby partner institutions maintain a crop collection on behalf of the region, as in the case of *Allium* species (as seed) and cruciferous crop collections in Wellesbourne, United Kingdom; the European field collection of long-day alliums at Olomouc, Czech Republic; the European field collection of short-day Alliums at Rehovot, Israel; and the wild Brassicas and related wild relatives collection in Madrid, Spain. The Government of Norway has established the Svalbad Global Seed Vault in the permafrost for safe storage of *ex situ* seed collections of world crops; it currently houses more than 500,000 accessions.

Characterisation and evaluation. The state of phenotypic characterisation across Europe is generally good by global standards. For example, approximately 90% of the accessions of cereals and legumes, 50% of root and tuber crops, 75% of vegetables, 80% of forages and 30% of underused crops conserved in Hungary have been characterised and evaluated. The Czech Republic has comprehensive data on morphological and agronomically important traits, including abiotic and biotic stresses. In Romania, about 20% of the accessions in the national genebank have been phenotypically and biochemically characterised.

Information and documentation. The state of plant genetic resources documentation is also, in general, good in Europe, although a variety of tools are used for data storage and management. Standardised passport data from 38 countries are published by EURISCO, and the ECPGR network has also supported the establishment and maintenance of nearly 50 European Central Crop Databases that compile and disseminate characterisation and evaluation data of several crops.

Exchange. The extent of germplasm movement in Europe and the availability of associated data varies considerably among countries. While there has been little movement of germplasm from Romania for example, Germany's IPK has distributed about 710,000 samples during the past 60 years to various users. A survey on the ITPGRFA indicates that scientists are not experiencing specific difficulties in exchanging plant material (Appendix 2).

Education. In Europe, various universities provide courses in agricultural sciences, plant breeding, and plant science, which include aspects of plant genetic resources (Box 6). Formal BSc, MSc and PhD degree programmes with special emphasis on biodiversity

Box 6 Examples of post-graduate degree programmes in genetic resources and agrobiodiversity

Belgium

Katholieke Universiteit Leuven – MSc in Tropical natural resources management

Germany

University of Hannover – Plant biotechnology

University of Göttingen – Conservation and sustainable utilization of plant genetic resources in South-east Asia

Italy

Scuola Superiore Sant' Anna – Doctoral Programme in Agrobiodiversity

The Netherlands

Wageningen University – MSc in Plant sciences (plant genetic resources) and in Plant biotechnology (functional plant genomics)

Spain

Universidad Politecnica de Madrid – Programa de Postgrado Oficial en Biotecnologia y Recursos Geneticos de Plantas y Microorganismos Asociados

Institute of Zaragoza – International Masters in Plant breeding

United Kingdom

University of Birmingham – MRes in Conservation and utilisation of plant genetic resources

University of East Anglia – MSc in Plant genetics and crop improvement and genetic resources have been established in several countries as a response to calls for action by the CBD. In some countries, genebank staff are engaged as university faculty members on an adjunct or part-time basis, and various institutions, societies, non-governmental organisations (NGOs), and a few national genebanks offer short courses (workshops, seminars) on practical aspects of PGRFA. The United Kingdom has a long tradition of MSc courses on collection and characterisation of PGR, recently expanded to include the safeguard of wild species. Italy has promoted and finances a PhD programme for enhancing human resources from developing countries in the evaluation of PGR. Courses on collecting and conservation techniques are very much in demand, especially in eastern Europe.

6.4 European Commission action

The European Community's action aiming at the preservation of plant genetic resources began in the 1970s, when the Directorate General for Agriculture established a Committee for Gene Banks and Resistance Breeding, with the aim of harmonising the conservation and valuation of PGR. The Committee, in co-operation with scientific societies, held a series of meetings on specific issues, such as seed regeneration in the collections (Porceddu and Jenkins, 1981). In 1993 the EU became a contracting party of the CBD and the following year co-financed the First Community Programme, aiming to learn more about genetic resources in agriculture, to promote their conservation, characterisation, collection and use, to develop data as well as quality control standards, and to bring together national knowledge and knowhow present in decentralised databases (Hall, 2009). The programme, which ran from 1996 to 2000, co-funded 21 projects, considering 4 animal and 17 plant species, with an expenditure of €9 million (see Appendix 4 for details).

In 2004 the EU became a contracting party of ITPGFRA and, with Council Regulation (EC) No 870/2004, established and co-funded with €10 million the Second Community Programme on the conservation, characterisation, collection and use of genetic resources in agriculture, comprising 17 actions (see Appendix 4 for details).

The 2003 and 2004 CAP reforms and the related Council Regulations have offered opportunities at the national and regional level for financing additional plant genetic resources preservation activities, including a set of amendments to EU seed legislation to allow the marketing of conservation varieties (see Appendix 4 for details).

Based on this extensive experience, it can be concluded that the Europe has an established tradition of co-operation, which generated important benefits in the conservation and use of plant species important to European agriculture. However, there remain major gaps in conservation, particularly with respect to crop wild relatives and in the development of effective strategies for their use. Generally, the EU initiatives have been beneficial but their organisation has not permitted the development of a sustained strategic programme. It is important to do better in supporting and using co-ordinated research in plant sciences to improve the knowledge base on the conservation and application of PGRFA (see Chapter 8). Further information on examples of recent and current research projects funded by the European Commission are provided in Appendix 5. Approximately two billion euros are being invested for collaborative research on 'Food, Agriculture, Fisheries and Biotechnology' for the period 2007–2013 in the seventh Framework Programme: this is a substantial investment and it is vital that the outputs are translated into practical application.

7 Needs and opportunities: the developing policy agenda

7.1 Introduction: CAP reform

As noted in Chapter 5, agriculture policy has been central to the EU's strategic development, and this policy continues to evolve. In the future, agriculture will remain in the front line for combating societal challenges. The European Commission's policy to address rising global food prices includes a strand of action '*Increasing agricultural supply and ensuring food security in the longer term*' which includes boosting agricultural research to increase productivity (document A in Box 7). In November 2010, the Commission revealed its blueprint for reforming CAP, recognising that the EU should be able to contribute to world food demand and reinforcing the strategic linkage of subsidies to farmers to environmental and food security goals (document B in Box 7). Output from the third Foresight Exercise of the Commission's Standing Committee on Agricultural Research (document C in Box 7) presents a case for radical changes in food consumption and production in Europe to meet the challenge of scarcities and to make the European agro-food system more resilient in times of increasing instability.

Recent discussions on the total European Commission budget for the period 2014–2020 anticipate that the proportion of the budget consumed by the CAP will decrease whereas the total investment in research will increase.[8] The suggestion from DG Research and Innovation that money can be transferred from farm subsidies to pay for agriculture-related research is particularly significant.

A debate on the future of the CAP and its principles and objectives identified the shared targets, discussed in section 5.4. To achieve these targets, there is significant public support (reported in the survey cited in footnote 3) that the EU should, *inter alia*:

- ensure that the CAP guarantees food security for the EU;
- continue to push the competitive (and potentially competitive) sectors of European agriculture towards operating in a market context, giving more importance to innovation and the dissemination of research;
- recognise that the market cannot (or will not) pay for the provision of public goods and benefits; this is where public action has to offset market failure;
- protect the environment and biodiversity, conserve the countryside, sustain the rural economy, preserve/create rural jobs, mitigate climate change;
- introduce transparency along the food chain, with a greater say for producers;
- create fair competition conditions between domestic and imported products;
- avoid damaging the economies or food production capacities of developing countries;
- help in the fight against world hunger.

Loss of biodiversity is a global environmental threat which results in substantial economic and welfare losses. Despite efforts, the specific EU target to '*halt biodiversity loss in the EU by 2010*' has not been achieved and at its 2009

Box 7 Key EU policy and other documents

(A) Communication from the Commission to the European Parliament, The Council, the European Economic and Social Committee and the Committee of the Regions, COM (2008) 321 final, 'Tackling the challenge of rising food prices. Directions for EU action'.

(B) Communication, COM (2010) 672 final, 'The CAP towards 2020: Meeting the food, natural resources and territorial challenges of the future'.

(C) European Commission, Standing Committee on Agricultural Research (SCAR), February 2011, 'Sustainable food consumption and production in a resource-constrained world', http://ec.europa.eu/research/agriculture/scar/pdf/scar_feg3_final_report_01_02_2011.pdf.

(D) Communication, COM (2010) 4, 'Options for a EU vision and target for biodiversity beyond 2010'.

(E) Communication, COM (2011) 244 final, 'Our life insurance, our natural capital: an EU biodiversity strategy to 2020'.

(F) Commission Staff Working Document accompanying the White Paper, COM (2009) 147, 'Adapting to climate change: the challenge for European agriculture and rural areas'.

(G) Communication, COM (2008) 862 final, 'Towards a coherent strategy for a European Agricultural Research Agenda'.

(H) Joint Programming Initiative, June 2011, 'Agriculture, food security and climate change', http://www.faccejpi.com.

[8] European Commission Press Release, 29 June 2011, 'Investing today for growth tomorrow'. Available on http://ec.europa.eu/budget/reform (Multiannual Financial Framework 2014–2020).

meeting on the environment, the EU Council called for a new EU vision and target for biodiversity, beyond 2010.

The Commissioner organised a series of consultations with stakeholders (document D in Box 7) resulting in a broad consensus that the EU long-term (2050) vision for biodiversity should accord with the general principle: '*Biodiversity and ecosystem services – the world's natural capital – are preserved, valued and, insofar as possible, restored for their intrinsic value so that they may continue to support economic prosperity and human well-being as well as avert catastrophic changes linked to biodiversity loss*'. The 2020 target is to halt the loss of biodiversity and degradation of ecosystem services in the EU, and to restore them in so far as it is feasible, while stepping up the European contribution to avert global biodiversity loss.

Europe's biodiversity has historically been embedded in a rural environment. The EU's rural areas are a vital part of the physical make-up and the identity of Europe. Farming and forestry remain crucial for land use and for the management of natural resources in the EU's rural areas, and as a platform for economic diversification in rural communities. The strengthening of EU rural development policy is, therefore, an overall EU priority which brings together agriculture and environmental concerns. The EU's 2020 biodiversity strategy seeks to steer more CAP payments towards rewarding farmers and foresters for protecting the environment and this requires the development and incorporation of quantified biodiversity targets into EU rural development policy. In reiterating the key message found in previous documents, it was concluded that a major goal is '*to support genetic diversity in agriculture*' (document E in Box 7).

As well as providing essential raw materials, as described in EASAC (2009), the European countryside provides essential ecosystem services and plays a key role in adaptation to, and mitigation of, climate change. Thus cropland, forests and pastures have to provide food, fibre and other goods, renewable energies, water and biodiversity. A new paradigm has to be developed to facilitate and, at the same time, take advantage of these interactions between biodiversity and agriculture. This constitutes a major challenge in which PGRFA must play a central role (see Chapter 9).

7.2 Sustainability challenges

Restoration of ecosystem services, adoption of climate change adaptation and mitigation strategies and the development of more resilient production practices are an essential part of building sustainability, while maintaining competitive production. Key actions will need to include optimising the use of resources and of the available measures under the reformed CAP, notably to prevent the intensification or abandonment of farmland, woodland and forest and supporting their restoration. Thus, strengthening rural development policy with a view to strengthening the provision of ecosystem services by preserving and enhancing farming and forestry in the context of the CAP is essential.

As described previously, the policy approach of protecting special areas and encouraging a wider spread of low intensity agro-environmental schemes has had only a limited success, both in terms of income generation and in safeguarding biodiversity. New approaches are needed, therefore, based on an improved use of diversity.

The Royal Society report 'Reaping the benefits' (2009) proposes one alternative approach, which involves greater targeting with more '*intensive agro-environmental schemes, involving the restoration of habitats that are most important for flood protection, carbon sequestration, critical biodiversity and enhancing the health and quality of the life of the locals, linked with sustainable agricultural intensification*'. The production of more food and fibre on a sustainable basis are targets to be achieved by an '*intensive agriculture based on knowledge, technology, natural capital*'. Concurrently, agriculture based on the use of non-renewable inputs must decrease. This is particularly true for the use of nitrogenous fertilisation that in the future must come from biological fixation of atmospheric nitrogen through the use of leguminous plants, such as pulses and clovers, and of cereals which have been endowed with these mechanisms. Finding ways of reducing the process of de-nitrification by micro-organisms can also be expected to promote the sustainability of agriculture. Preparing for a future scarcity of phosphorus should also be actively considered (Neset and Cordell, 2011; Richardson and Simpson, 2011).

Land left free of crops needs to be returned to forest and permanent grassland instead of being largely abandoned. The ways forest, pasture and meadow plant species interact with each other, and with birds, insects and micro-organisms, need to be clarified to optimise their values and make their conservation successful.

To address these objectives, key areas for research include the following:

- understanding how inter- and intra-varietal diversity can reduce damage by pests and diseases;
- exploring plant-microbe interactions to improve soil structure, ecosystem regulation and supporting services;
- exploring and applying the concepts of ecosystem genetics within an agricultural framework;
- deploying diversity at all scales to reduce agriculture and environmental vulnerability and to improve crop adaptability.

Some of these issues are discussed in further detail in Chapter 8.

7.3 Climate change challenges

Climate change is expected to affect different EU areas to a varying extent, with the Mediterrranean region affected more than northern and central Europe (Fisher et al., 2002; see also section 2.2). It is important to take account of this potential variability when considering implications for agricultural policy.

The working document accompanying the Commission's White Paper on climate change (document F in Box 7) acknowledges the likely differences in impact in different regions of the EU and provides a good introduction to considering the implications for different crops and the adaptation response required by EU agriculture – including using genetic diversity – together with the development of the appropriate CAP tools to support adaptation. The research agenda is discussed in further detail in the Commission's Communication (document G in Box 7) on needs and directions for EU climate change research, emphasising that '*the interface between agriculture, climate change and energy constituted a major societal challenge that deserved to occupy a more prominent place on any future research agenda*'. The recent start of a Joint Programming Initiative (document H in Box 7) to provide a detailed climate change risk assessment for European agriculture and food security is an important strategic step in defining this necessary research agenda.

Adaptation to, and mitigation of, climate change will require a different kind of agriculture, one which combines higher levels of resilience with changed production practices and technologies, such as reduced tillage, and the generation of animal feed stocks that reduce methane production. Agriculture is estimated to be responsible for more than 10% of total greenhouse gas emissions in its direct effects and considerably more if including, for example, the impact of land clearance for agriculture. It is a major source of CH_4 and N_2O, which account for half of total emissions in the EU. In agriculture, main contributors to CH_4 emissions are enteric fermentation (71%) and manure (24%). The fermentation emission rates mainly depend on the type of digestion system and the type of feed intake. Breeding and selection of grasses and clovers for the ability to provide feed source of reduced emissions has been proposed, and analyses of genetic resources supporting such traits are needed (Powell, 2009).

Responding to the challenges of climate change will require increased use of PGRFA in many other ways involving, in particular, the search for new disease resistances and enhanced capacities to cope with abiotic stresses such as drought and flooding. Improving resilience and ecosystem function will require a much greater understanding of the interactions among plants and other organisms within agro-ecosystems. Optimising the benefits of knowledge-based plant breeding (EASAC, 2004), and securing the full advantages of knowledge-based PGRFA maintenance and use, will involve significant additional research to explore the interactions between plants and other organisms.

7.4 Productivity and crop diversification

Agricultural production is often not perceived as a priority for the EU. However, Europe is a net importer of a significant amount of food and feed. Moreover, the increasing demand for bio-energy crops and biomass for chemical feedstock (biomaterials) as well as the potential global food commodity shortages and the need to be more sustainable mean that Europe should be very concerned about production issues. Furthermore, there is an overdependence on a few crops in European agriculture, while a significant number of other crops remain neglected and underused. For all these reasons improvements in production, productivity and in the quality of agricultural products are still required.

There are significant opportunities for the development of new crops and their uses. The demand for second- and third-generation biofuels is likely to grow and be reflected in an increased interest in the identification and use of the necessary plant genetic resources (Graham-Rowe, 2011). There is also continuing pressure for the development of new crops – most obviously in the oilseeds area and for the domestication of species as potential biomaterial and medicinal crops. All of these factors increase demand for genetic resources and concomitant research on genomics, gene expression and physiology (Fears, 2007; Graner, 2009).

Crop diversification should be an important part of any dietary diversification strategy – that must also include support for public awareness and behavioural change – to tackle the rising rates of obesity and other diseases of over-consumption in the EU (see Chapter 8).

Taken together, these challenges will require a new knowledge-based approach where the ability of Europe's leading research centres to mobilise molecular biology skills and capacities can be used to improve the conservation and use of PGRFA. The research and innovation agenda will need to take account of the regional differences and diversity in agriculture across Europe. The next chapter outlines some priority areas where research on PGRFA could make a substantial contribution to improving the competiveness and quality of European agriculture and to achieving European societal goals.

8 Research priorities

8.1 Introduction

The identification and functional classification of genes and the detection of genome sequences that correlate with desirable phenotypes have helped to bring together the activities and objectives of molecular genetics and plant breeding. The former provides markers for exploring genetic variation, selecting traits and improving identification of potentially useful genotypes in segregating populations while the latter ensures that these are translated into the development of new crop varieties.

Plant breeding does not simply mean assembling genes; it also involves a knowledge of genetic variation. Genetic variation is the raw material for plant breeding, and many documents, including EASAC (2004), stress its role as a source of genes for desired traits. The analysis of genetic variation has a more profoundly relevant role in plant science, plant breeding included, than providing single genes. For example, it allows the following: insight into the evolution of genomes, the discovery of the genetic architecture of complex traits, the quantification and organisation of diversity at different levels, analysis of plant responsiveness to environmental stimuli, exploration of yield potential, characterisation of plant interactions with other useful organisms, and understanding of tolerance and resistance to biotic and abiotic stresses. Thus, different species and populations within species – wild and cultivated, annual and perennial – may have different strategies to cope with biotic and abiotic stress and different pathways contributing to productivity: this is why genetic resources are an irreplaceable research material. The use of genetic resources makes possible the analysis of the phenotypic variation that endows plants with genetic adaptability or functional stability and in this role genetic resources foster new links between molecular biology, ecology and evolution and new knowledge of adaptation and stability.

There have been significant scientific and policy developments since EASAC's report in 2004. These include the following, as described in previous chapters:

- Increasingly comprehensive documentation of the global status of the relevant resources (FAO, 2010) (Chapter 3).
- Introduction of the ITPGRFA (Chapter 4).
- Rapid methodological advances in plant gene sequencing and the use of 'omics' technologies (a collective term for several high-throughput techniques developed for the comprehensive analysis of the molecular components of biological systems), often capitalising on research advances in other sectors (especially health research (Fears, 2007)) (Chapters 2 and 6).
- Renaissance of agriculture as a political priority (Chapters 5 and 7).

Nonetheless, we believe that our earlier recommendations (EASAC, 2004) on genomics and genetics continue to be relevant and we reiterate '*European agriculture will take advantage of these newer opportunities only if a coherent EU science and innovation strategy is developed to integrate currently fragmented research efforts, to tackle barriers to progress, to focus on reduction to practice, and to allow technology and information to be presented to plant breeders in a suitably practicable form.*'

Universities, institutions and research organisations in the EU have a strong tradition of research on the conservation and use of PGRFA (see Chapter 6). Many research groups in Europe have made contributions of global significance over many years.

It remains evident that a significant disconnect frequently exists between the institutions and scientists involved in the maintenance of genetic resources and those involved in their use. This disconnect is often reflected in the organisation of research projects, where the two areas – conservation and use of genetic variation – are poorly linked. These should be considered as missed opportunities for conservation research to fully benefit its users and for the users to make the best use of the diversity conserved in gene banks. The European plant genetic resources conservation community has a long tradition of collaboration and has maintained a functioning collaborative framework for over 30 years (ECPGR, see section 6.2). However, this role in providing and mobilising conservation plant genetic resources may not have been fully appreciated by the PGRFA user community or by those involved in more fundamental aspects of plant biology.

It is EASAC's contention that the next decades must capitalise on an increasing use of PGRFA to meet the emerging agricultural challenges that Europe faces. This will require better strategies to avoid the loss of the existing diversity but also the adoption of new approaches to the identification and deployment of that diversity needed to meet the new challenges.

Recent developments in plant biology and molecular genetics and the work performed on model species provide unprecedented opportunities to improve the conservation and use of PGRFA and their better deployment (Koornneef, 2009). The molecular analysis of collections of thousands of accessions is now routine. At the same time, investigation of the extent and distribution of diversity combined with geographic information systems (GIS) and other informatics tools, provide unrivalled insights into the variability that is potentially available for use. Search strategies are being refined to make the detection of useful traits in entire collections a feasible proposition. Thus ecological and population genetic research can now support the deployment of diversity and link deployment strategies with more sustainable agricultural practices.

We agree with the analysis presented recently by the European Technology Platform, Plants for the Future[9], that '*CAP needs to be aligned with the increased innovation requirement of agriculture in an increasingly competitive market for agricultural goods and services in Europe and globally*'. To develop this co-ordinated research and innovation strategy, we advise that it is necessary to consider what should be done across a broad front to clarify research priorities, identify research capacity requirements (relating to funding, training and organisational infrastructure), determine and agree what is necessary to translate research outputs into sustainable agriculture, and explore the issues for the EU in the global context, for example ensuring good linkages with CGIAR. One pervasive element in all of these research and innovation objectives is the vital importance of building cross-disciplinary connections between molecular biology, plant sciences, ecology, agronomy and with the social sciences, for example to understand and inform the human behavioural response to change.

During the workshop held in Rome in 2009 (Appendix 1), many topics emerged where an increased research effort was considered necessary. For the purposes of this report, these topics have been organised into four main subject areas:

- understanding fundamental aspects of plant biology;
- improving conservation science;
- mobilising diversity to enhance sustainable productivity increases;
- deploying diversity in production systems.

We now describe some of these areas in more detail.

8.2 Fundamental aspects of plant biology: using diversity to understand genome organisation and plant speciation

The continuous development of advanced molecular tools generates waves of new knowledge on plant genomes. In this situation plant genetic resources have become increasingly valuable as research tools for further advances. The materials used for research can be carefully chosen to sample fully the diversity of a target genepool. The crop and its close relatives can be studied to improve our understanding of the organisation of different genomes, as well as the different properties of genomes, including gene distribution and expression.

1. Recombination and linkage disequilibrium

The management of recombination is central to the development of improved varieties. Recombination allows the creation of new gene complexes, permitting the identification of new, more desirable, combinations of specific traits although it can also lead to the loss of existing adapted gene complexes. Work on understanding the nature and extent of recombination and of linkage disequilibrium in crop species has already produced important results concerning search strategies for useful genes, better designed crossing programmes and the identification of co-adapted gene complexes (Tanskley and McCouch 1997; Peleman and van der Voort, 2003; Tenaillon and Tiffin, 2008; Tenaillon, 2009).

2. Evolution, speciation and domestication

There has been exciting progress in understanding genome organisation in crop plants. The availability of the complete DNA sequence for *Arabidopsis*, rice and other crops marks the beginning of a new era of research which allows a precise appreciation of the nature and extent of diversity at species and intraspecific levels (Powell, 2009). Genetic differences can be followed at different levels from changes in gross morphology to differences in DNA sequences and the process of speciation and domestication can be analysed in terms of sequence divergence. Polyploidisation and chromosome rearrangement have played an important part in plant evolution. Understanding the concept of the 'pan-genome', as in maize, the relationships between different species and the molecular structure of chromosome rearrangements resulting from polyploidisation will have a significant impact on conservation decisions and on the use of conserved materials (Morgante, 2009). Research priorities that have been identified include the need to explore further the existence and nature of pan-genomes, the re-sequencing of entire genomes of multiple individuals and the need for an improved understanding of the mechanisms and rates of the emergence of new variation, the relative role of regulatory versus coding variation and the functional roles of non-coding DNA.

3. Neutral and adaptive variation

A long-standing issue in population and evolutionary genetics is how much of the variation present in nature

[9] Response to Consultation on EU research and innovation funding programmes, http://www.plantetp.org/index.php?option=com_docman&task=doc_download&gid=163.

within a species is neutral with respect to fitness or is under selection, and therefore of adaptive significance (Koornneef, 2009). Beside the scientific relevance of such a question, it is also of practical interest when it comes to the conservation of genetic resources. At present, while there are many ways of estimating neutral variation in a collection of plants, it is difficult to provide data on the adaptive component of the variation. What is lacking is the information on the genes and on their mutations that are of adaptive significance. A major effort is therefore required to identify such genes (in most cases quantitative trait loci, QTL genes) and the adaptive mutations within them (quantitative trait nucleotides, QTN).

4. Epigenetics

Recent studies have demonstrated the importance of epigenetic factors in shaping phenotypes (Tigerstedt, 2009). The discovery of a deeper layer of genetic regulation from the action of non-coding RNA has challenged the traditional view of the relationship between genotype and phenotype. Research on the elucidation of this component of gene regulation should not be restricted to model species: the existing variability of epigenetic nature should become one of the priorities for future research on crop plants. There remain differing views on the importance of epigenetics, its role in plant population diversity, its contribution to adaptation and domestication, and its practical relevance. Carefully designed research projects using selected plants and populations are needed. The results are likely to have a significant effect both on plant genetic resources conservation strategies and on breeding programmes.

8.3 Improving conservation science

Fundamental to any research agenda concerned with unlocking the full potential of PGRFA is their effective maintenance or conservation, together with the development of methods which ensure their long-term availability for present and future users. Because resources are always finite, choices must be made as to what to conserve. The very differing biology of species of agricultural interest suggests that decisions have to be made not only on what to conserve but also how and where to conserve.

1. Understanding the amount and distribution of variation

The amount and distribution of genetic variation is influenced by the breeding system of a species. This affects the extent and pattern of linkage disequilibrium and, thus, allows the adoption of association mapping strategies. Distribution and patterns of polymorphism reveal the signature of demographic events and past selection, thus allowing an understanding of the evolutionary processes experienced by a genotype under different environmental conditions. Of equal importance is the understanding of the molecular genetic structure of populations, as it reflects their geographic distribution, the variation among and within populations across the species range, the differences between wild and cultivated materials and the importance of gene flow (Tenaillon, 2009).

Substantial progress has been made in understanding the extent and distribution of genetic diversity in crop gene pools. The advent of a range of molecular methods and the ability to deploy them on a large scale support the conclusion that future conservation decisions will be increasingly based on the distribution of neutral and adaptive variation. For crop wild relatives and other useful wild species, GIS analyses provide relevant information for conservation decision-making and in the identification, for any given level of resource availability, of populations and materials to be conserved and of the conservation method.

2. Conservation practices

Although, progress has been made during the past decade in farm conservation of traditional varieties (Jarvis et al., 2008, 2011), there has been much less progress with respect to *in situ* conservation of useful wild plants, especially crop wild relatives (Heywood and Dulloo, 2006). Interestingly, despite the undoubted capacity of molecular methods to help the further development of *ex situ* conservation practices, little research in this area has been published. There is a need for analyses of such key questions as the optimum population size of samples maintained in gene banks, the decay of diversity in collections, and the effects of different regeneration practices. Molecular methods now offer the possibility of genotyping entire collections. The ways in which this should be done and combined with new approaches such as genome re-sequencing need to be investigated to increase the value of collections for users. *Ex situ* and *in situ* conservation meet different needs: the former secures current diversity, the latter allows for continuing evolution. The ways in which they are best combined have not been sufficiently studied to ensure that emerging challenges, particularly in response to climate change, can be met.

3. Monitoring erosion, vulnerability and developing indicators of diversity

The EU has played an important part in the development and testing of biodiversity indicators, and this has included the monitoring of diversity in agro-ecosystems. However, there is still lack of good indicators of genetic and crop diversity in production systems, something that would allow decision-makers to determine the extent of genetic erosion in different crops and an assessment of their potential genetic vulnerability and thus improve the cost effectiveness of conservation efforts. Tools are beginning to be developed which open important perspectives on the erosion of major crop diversity in Europe, but these need to be rigorously tested on a wide range of crops.

4. Strategies for crop wild relatives

A specific research challenge concerns the development of improved conservation practices for crop wild relatives and for neglected and underused species (Maxted and Kell, 2009). The challenge has two dimensions: first, these two groups of PGRFA are under-conserved and under-represented with respect to both *in situ* and *ex situ* conservation programmes; secondly, as has been clearly shown for crop wild relatives, climate change is likely to increase the vulnerability of these species and crops. As some estimates have placed the proportion of European plant species that can be regarded as crop wild relatives as high as 70% (Kell et al., 2008), this is clearly not a trivial problem.

8.4 Mobilising diversity to enhance sustainable productivity increases

The growing size of *ex situ* collections of PGRFA has been cited as a major obstacle to their use. Researchers, plant breeders and other users often have only limited capacity to use materials present in gene banks which can contain many tens of thousands of accessions. Nonetheless, this wealth is also the key to improved knowledge on how to use PGRFA for improving crop production and what to choose to be introduced into breeding programmes. It provides also the resources needed to understand what constitutes adaptive diversity, how adaptive gene complexes are developed and maintained, and how useful traits can best be detected in large collections of material (von Bothmer, 2009).

1. Identification of genes underlying phenotypic/adaptive variation

Understanding the evolution of ecologically important traits requires the identification of polymorphisms with functional effects on phenotypic differences (Salamini, 2009). Such polymorphisms are also important for elucidating gene functions and genetic pathway architecture. In this case, the role of natural variation is particularly important because experimental strategies based on genetic analysis of induced mutations may not be applicable or may not be suitable for detecting phenotypic effects owing, for example, to gene redundancy. Relationships between phenotypic differences and the underling alleles may also be affected by environmental interactions and genetic background. QTL–environment interactions are not rare: the phenotypic effect of certain QTLs may be detectable in a specific environment but not in others, or the magnitude of their allelic configurations may differ (Powell, 2009). The molecular basis of the relationship between QTLs and genotype–environment interactions at the whole plant level still have in large part to be elucidated.

Functional interaction among genes at different loci represents a fundamental force affecting many aspects of plant adaptive evolution. In this context it is important to identify the loci and the chromosome regions involved, the underlying genes and the genetic polymorphisms possibly associated with phenotypic variation.

2. De novo creation of variation

Recent studies on molecular variation in plants have shown that a large fraction of the variation present at the DNA sequence is from relatively recent insertions of transposable elements of different classes, both DNA transposons and long terminal repeat (LTR) retrotransposons. What remains to be studied is how much of this variation is functionally relevant, i.e. affects phenotypic variation, and how much of it is continuously created during the breeding process (Morgante, 2009). This topic is of great relevance for genetic analysis addressing the origin of existing genetic variation in relation to the crop domestication process, i.e. what variation pre-existed crop domestication and what arose after domestication, and the rate at which new variation is continuously created.

3. Identification and selection for complex characters

Various crops, such as wheat, rice and maize, are grown under a broad range of climates and agricultural systems and are broadly adapted to a very wide range of environments. Many wild relatives also demonstrate that the genepool of some crops has a wide range of adaptation, with related species adapted to quite different environments. Examples include rice, wheat, *Brassica* crops, and beet.

Many phenological events, such as seed setting and germination, require proper timing across different climatic regions. Variation in these ecologically important traits has been investigated in model plants under controlled environments (Koornneef, 2009). However, little is known on what takes place under natural conditions, even less for crop plants and their wild relatives. A well-studied example in wheat is vernalisation, where spring varieties are produced by loss of vernalisation requirements because of mutations in known regulatory genes, but additional genetic variation occurs which is due to loci with unknown location.

Important unresolved questions include whether the observed variation among populations represents adaptive differentiation in response to divergent natural selection, or the extent to which trait variation is associated with variation in climate, soil or other environmental factors (von Bothmer, 2009). We also lack information on traits and underlying molecular mechanisms explaining the higher fitness of local genotypes – information essential to the achievement of an improved sustainability in agriculture.

4. Detecting useful traits

Methods have been developed and tested which combine the analysis of extent and distribution of genetic diversity and GIS data with the aim of locating useful traits. Such methods currently operate with greatest efficiency on simple traits with specific geographic distribution, such as disease resistance in wheat. In other cases, such as for abiotic stress, the results have been less clear-cut. However, a knowledge of eco-geographic factors combined with the analysis of diversity patterns can support the identification of useful traits among lines present in large collections. As information on genes improves and automated molecular sequencing techniques become available, it should be possible to develop a new generation of search strategies, such as allele mining, which are likely to make a qualitative difference in support of our capacity to find accessions with useful traits. While allele mining reduces time and efforts required for the discovery of novel resistance alleles, it depends on the availability of well-characterised and precisely localised genes.

Priorities for the development of improved search strategies are as follows:

- high-quality sequences of crop plant genomes to provide rapid access to genes;
- development of populations for trait mapping;
- increased efforts for phenotypic analysis under standardised and field conditions;
- creation of infrastructures for bio-banking (laboratory work, databases, bioinformatics).

Realising the increased benefits to agriculture from the increased use of PGRFA will require increased investments in pre-breeding. This is time-consuming and its outcome is limited by, for example, the numbers of crosses that can be made between a crop and its wild relative. One suggestion is to explore the development of a European level institute of pre-breeding, capable, through economies of scale and concentration of expertise, to develop a significant pre-breeding programme for several crops, in support both of public and private sectors.

8.5 Deploying diversity in production systems

Agriculture in developed countries has been characterised by ecological simplification and the replacement of natural processes by intensive cultivation and increasing energy and chemical inputs. The result has been that ecosystem service provision has been reduced in agro-ecosystems and, in the worst cases, this has been accompanied by land degradation, pollution of surrounding areas and reducing returns to farmers. The knowledge and technologies are now beginning to become available to achieve what has been called sustainable crop production intensification. One component of this is the improved use and deployment of agricultural biodiversity, particularly PGRFA.

1. Population creation and management

The development of composite cross populations or modern landrace-type populations has been shown to complement the traditional pedigree breeding methods and to provide populations and varieties that are able to adapt to changing conditions (Tenaillon, 2009). Combined with participatory plant breeding, these approaches are likely to be appropriate for minor crops, where local adaptation is important and investments from major multi-national breeding companies will always be insufficient. These approaches need to be tested further to explore how they can contribute to increased ecosystem functionality, to stability in production and to increased diversity in production systems.

2. Plant–micro-organism co-evolution

Micro-organisms, both pathogenic and beneficial, are thought to be important factors in shaping the genetic structure of plant population. Much work has focused on aspects of resistance to pathogenic organisms and to the deployment of resistance genes (Keller, 2009). The ways in which plant and soil micro-organisms interact, the contribution to the production of vesicular/arbuscular mycorrhisa, the recombination events that can occur between virus and plant, and the many other complex interactions that affect production that are not part of simple disease relationships, have scarcely begun to be investigated (Bonfante, 2009).

Integrated pest management (IPM) approaches have made substantial contributions to improving sustainability in European production and reducing the cost and environmental damage arising from the use of chemical sprays. However, one underused component of IPM has been the diversity within the crop plants – both in terms of deployment of much more diverse ranges of varieties and of the use of varietal mixtures or multilines.

The use of mixtures to improve disease management has been tested by several European research institutes with largely positive results (Ostergard et al., 2009), and this raises important questions on how optimally to deploy a range of resistance genes without the need constantly to return to the breeder for a new source of resistance or, as an alternative, without the increased use of pesticides.

3. Improving adaptability and resilience

Climate change and increased climate variability support the need to prioritise sustainability as an explicit objective. This has led to the conclusion that new cultivars should contribute to increased adaptability and resilience in agriculture (Stamp, 2009). Adaptability is needed because the conditions under which production occurs become less predictable with respect to water availability, temperature and other environmental variables (Karamanos, 2009). Resilience, the ability to recover after a shock or stress, is also required to secure production under adverse conditions of, for example, the invasion by new pathogens. A new area of science able to contribute to improving production systems is ecosystem genetics and this new discipline may also be of particular relevance to pastoral and forest production systems.

4. Dietary diversity and health

Increasing income levels together with improved production and increased investment and marketing by the food industry have led to increased levels of obesity in Europe. There is currently a need to change eating habits to improve health in the population. European agriculture will have to meet the health challenge and contribute not only through the quality of produce, but also through the variety of products (Frison, 2009). Dietary diversity has been shown to be associated with improved health. The availability of a diverse range of grain, pulse, vegetable and fruit products, combined with efforts to inform behavioural attitudes, lies at the basis of improving dietary diversity. To achieve this, research is needed on a much wider range of crops to offset the concentration tendencies of the past 40–50 years, which have seen a few major crops dominate the research agenda. PGRFA analyses will be needed to identify and develop commercially viable varieties which may be integrated into more diverse production systems.

9 Conclusions and recommendations

The CAP has contributed to the intensification and specialisation of agricultural systems. It has produced positive effects on yield, production and farmers' income, helping to ensure food security and safety, as well as a reasonable standard of living for farmers. However, CAP-induced changes have significantly affected the environment, including the disappearance of much valuable crop diversity that characterised the European mixed farming and Mediterranean agriculture. This is the variation that still provides the source of genes and gene complexes for future breeding, will be central to agricultural adaptation to climate change and remains the foundation of new knowledge on evolution, ecology and genetics. Plant genetic resources for food and agriculture remain the essential basis for plant breeding, for the management of natural and agricultural systems and for future food security.

The European Commission and Member States' governments have taken measures to safeguard much of this material: approximately two million samples are presently stored in *ex situ* gene banks. However, several crops are significantly under-represented in these collections, and the conservation and description of crop wild relatives is far from being complete. In previous chapters we have described in detail how this situation can be improved and issues for the research agenda are specified in detail in Chapter 8.

Our broad conclusions on the conservation and use of PGRFA, discussed in the present chapter, are relevant to multiple policy issues; for biodiversity conservation and securing a better environment, for improving land use and rural well-being, for improving sustainability, in preparing for climate change, and in creating a healthier and better nourished European population. Our main points for developing an expanded role for PGRFA, that we consider to be important to bring to the attention of policy-makers in the European Parliament, European Commission and Member States, are summarised as follows.

(1) It is imperative that commitment to conservation of PGRFA and related species and to the activities of conservation research is strengthened. Particularly urgent in our view are actions geared to facilitate progress in those EU countries where the PGRFA activities started more recently.

(2) We advise that it is equally important to develop improved frameworks to support the collaboration between PGRFA conservation agencies, especially in respect to research and action on *in situ* conservation. Only in this way can the resource base of European agriculture be secured.

(3) We emphasise that conventional action on biodiversity conservation alone is not sufficient. Increases in agricultural productivity can mean that less cropland may be used, making available large areas for other purposes. However, the policy approach which has been adopted – protection of special areas and encouragement of a wider spread of low intensity agro-environmental schemes – has had limited success, both in terms of farmers' income generation and in safeguarding biodiversity. An alternative approach foresees more intensive agro-environmental schemes, involving restoration of habitats that are important for flood protection, carbon sequestration, critical biodiversity, and health and quality of life. This is sustainable intensification based on knowledge, technology, natural capital and intensive agriculture (Royal Society, 2009). An essential contribution to this agenda will be a new integrated collaborative policy framework that supports both conservation and use of PGRFA.

(4) There is an urgent need to strengthen the collaboration between conservation scientists and plant breeders aimed at identifying PGRFA which provide genes and gene complexes able to support an agriculture in which the use of non-renewable inputs, such as fertiliser, pesticides and protectants, is decreased and replaced by the sustainable exploitation of biological resources.

(5) There is also need for a co-ordinated EU-wide research programme that would provide the knowledge base to determine the ways in which the deployment of diversity in agricultural production systems at different scales can contribute to improved sustainability and enhanced delivery of ecosystem services in ways that are competitive and support rural livelihoods. In addition to generating biological resources for the preparation of planting material, research on genetic resources and molecular breeding can provide knowledge on how to devise and optimise their management strategies. An essential element in developing sustainable production systems and achieving conservation objectives will be a new agenda for research on the way forest, pasture and meadow plants interact among themselves and with birds, insects, and micro-organisms. We emphasise that this work will require the creation of improved frameworks to support collaboration between PGRFA conservation specialists and users, including plant breeders and researchers in ecology, genetics, genomics, genecology, and other relevant disciplines.

(6) Climate change is expected to have a considerable effect on agriculture and food production worldwide, with losses and gains in crop and animal production and with marked variation in different European regions. Adaptation to, and mitigation of, climate change will require different genotypes and different agricultural systems, which combine higher levels of adaptability

and resilience with changed production practices. New cultivars will be needed throughout Europe adapted to the emerging situations. Crop wild relatives, minor crops and pasture plants must be considered an invaluable resource in breeding for adaptation and mitigation. These objectives require additional attention to conservation of crop wild relatives and minor crops and an increased public commitment to pre-breeding activities. We suggest that one cost-effective strategy to achieve the required economies of scale and concentration of expertise would be to establish a limited number of public institutions with regional responsibility for these activities.

(7) Food production has not been perceived consistently as a priority for the EU. Specialisation has created an overdependence of Member State economies on a few crops, while a significant number of crops remain neglected and underused, in spite of their nutritional properties. The demand for safe and healthy food and the rising rates of obesity and other diseases associated with over-consumption underscore a growing need for delivering food quality. To achieve these quality goals, development of varieties with improved attributes is desirable. Dietary diversification, based on increasingly diversified production, will also contribute to the provision of ecosystem services and will help to reduce genetic vulnerability in EU crop production.

(8) Significant opportunities exist for the development of new crops or crop uses. The increasing interest in crops as biofuels or sources of medical products may seem to have a negative impact on food security, but demand for new applications is likely to grow and the consequences of this have to be taken into account in policy development.

(9) Interdependence and collaboration within Europe and between European institutions will be central to mobilising PGRFA more effectively and to achieving the objectives of sustainable intensification and adaptation to climate change. Access to PGRFA that originate and are found outside Europe will also be of critical importance. Thus, the EU must remain active in the policy arena to help create a more open system of PGRFA exchange within the framework of ITPGRFA. European insitutions should also work to achieve greater global collaboration on PGRFA conservation and use. EASAC will explore how it may best work with other academies around the world to strengthen effective policy collaboration on shared objectives.

All of these needs and goals should be reflected in an increased commitment to the identification and use of plant genetic resources and the establishment of closer links between conservation and the advanced research relevant to their use (genomics, gene expression, informatics, physiology and cognate sciences). Challenges for sustainability, the response to climate change, productivity and crop diversification all require the generation and mobilisation of new knowledge. In summary, the EU's research centres must capitalise on molecular biology and other skills, and develop capacities to improve the conservation and use of PGRFA, thereby making a substantial contribution to competitiveness and quality of European agriculture and to the welfare of European citizens.

List of abbreviations

AEGIS	A European Genebank Integrated System
AVRDC	Asian Vegetable Research and Development Centre
CAP	Common Agriculture Policy
CBD	Convention on Biological Diversity
CGIAR	Consultative Group on International Agricultural Research
CWR	Crop wild relative
EASAC	European Academies Science Advisory Council
EC/PGR	European Cooperative Programme/Genetic Resources
ECPGR	European Cooperative Programme for Genetic Resources
EPGRIS	European Plant Genetic Resources Information Infra-Structure
EUCARPIA	European association for plant breeding
EUFORGEN	European Forest Genetic Resources
EURISCO	European Search Catalogue for Genetic Resources
FAO	Food and Agriculture Organization of the United Nations
GB	Governing body
GDP	Gross domestic product
GVA	Gross value added
IARCs	International Agriculture Research Centres
IBPGR	International Board for Plant Genetic Resources
IP	Intellectual property
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
IU	International Undertaking on Plant Genetic Resources
LR	Landrace
MTA	Material Transfer Agreement
NGO	Non-governmental organisation
PGRFA	Plant genetic resources for food and agriculture
QTL	Quantitative trait loci
QTN	Quantitative trait nucleotides
SMTA	Standard Material Transfer Agreement
SOW1	First Report on the State of the World's Plant Genetic Resources
SOW2	Second Report on the State of the World's Plant Genetic Resources
UNCLOS	United Nations Convention on the Law of the Sea
UNDP	United Nations Development Program
UPOV	International Convention for the Protection of New Varieties of Plants
WHO	World Health Organization

Appendix 1

Workshop

Plant Genetic Resources for Food and Agriculture

General aspects and research opportunities

Programme

Lamberto MAFFEI

Welcome address

Enrico PORCEDDU

Introduction

Session 1 – Plant Genetic Resources for Food and Agriculture

Chair: G. T. SCARASCIA MUGNOZZA

Alvaro TOLEDO

Plant Genetic Resources: their strategic role in achieving global food security and sustainable agriculture

Shakeel BHATTI

The International Treaty on Plant Genetic resources for Food and Agriculture

Emile FRISON

The multiple contributions of agro-biodiversity to food and nutrition security and to sustainable agriculture

Barbara VINCETI

The European Cooperative Programme on Plant Genetic Resources

Timothy HALL

EU activities on Agro-Biodiversity Research

Discussion

Session 2 – Opportunities for research

Chair: Antonio GRANITI

Wayne POWELL

A new era for plant genetic resources based on emerging genome approaches

Peter STAMP

Swiss maize landraces – a discovery and rediscovery

Andreas KARAMANOS

Drought resistance potentialities of Greek bread and durum wheat landraces

Beat KELLER

Unlocking genetic diversity from the gene pools of wheat and its relatives

Andreas GRANER

Utilisation of Plant Genetic Resources: Opportunities and Constraints

Paola BONFANTE

Plants and mycorrhisal fungi: an ancient ally for today's agriculture and food

Session 2 – Opportunities for research Cont.d

Chair: Alessandro PIGNATTI, G. B. KISS

Maarten KOORNNEEF

Arabidopsis natural variation as model for biodiversity research

Michele MORGANTE

A genome based view of plant biodiversity

Maud TENAILLON

Tracking adaptive changes, application for the management of genetic resources

Peter TIGERSTEDT

Pre-breeding and the epi-genetic issue

Roland VON BOTHMER

Diversity in wild and cultivated barley

Francesco SALAMINI

Use of molecular genetic variability in plant breeding

Discussion

Session 3 – Discussion on the contents of the Meeting Report

Chair: E. PORCEDDU

Toby HODGKIN

Points for the Meeting Report

Discussion

Conclusions

Sergio CARRÀ

In co-operation with

ACCADEMIA NAZIONALE DELLE SCIENZE DETTA DEI XL
ISTITUTO DI GENETICA VEGETALE (IGV), CNR
SOCIETÀ ITALIANA DI GENETICA AGRARIA (SIGA)
ASSOCIAZIONE AMICI DEI LINCEI
BIOVERSITY INTERNATIONAL

ORGANISING COMMITTEE: Sergio CARRA, Antonio GRANITI, Lamberto MAFFEI, Michele MORGANTE, Alessandro PIGNATTI, Enrico PORCEDDU (Co-ordinator), Francesco SALAMINI, Gian Tommaso SCARASCIA MUGNOZZA

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Preparation of the draft EASAC report, using the presentations and discussion at the workshop, was led by Toby Hodgkin and Enrico Porceddu on behalf of the Lincei Academy. Early drafts were revised after further discussion with workshop participants. A late draft was revised after discussion with Robin Fears (EASAC Biosciences Programme) who also consulted colleagues on the EASAC Biosciences Steering Panel. The final draft was peer reviewed by independent scientists nominated by EASAC.

Appendix 2 Results from a survey

To gain first-hand information on the role played by plant genetic resources in the most recent evolution of European agriculture, their expected role in the future, what Directives or specific legislation have been enacted to accommodate the treaty requirements and provisions, the Accademia Nazionale dei Lincei performed a survey, by a questionnaire structured into three parts. The first part dealt with the PGRFA role on the evolution of the country's agriculture and agribusiness and the value stakeholders attach to them; the second was intended to analyse the mechanisms of PGRFA exchange and the difficulties experienced in obtaining and supplying material; the third part dealt with issues related to ITPGRFA implementation. The questionnaire was sent to scientists, members of EUCARPIA and active in relevant EU Member States' organisations, including breeding companies, Research Institutions, universities, Governmental Departments and NGOs. The survey invited respondents to provide institutional assessment, although some sections of the questionnaire had to be completed by scientists working on specific crops.

Replies were obtained from over 30 organisations in 12 countries; scientists from two countries consulted among themselves to produce a collective answer.

In general, the survey indicated that plant genetic resources are assessed almost unanimously as important/very important and are expected to remain so in the future, owing to the strong dependence of European agriculture on foreign genetic resources, the present narrow base of crops, and the need for genes for new traits, such as those for biological resistance to diseases and tolerance to environmental stress, and climatic change. Specific points can be summarised as follows.

1. More public organisations than private ones answered. Private organisations were involved both in research and commercialisation, whereas public institutions were mainly devoted to research (applied) or have research and teaching duties (universities). Most respondents were active in plant breeding, including germ plasm evaluation and enhancement; most of them also have conservation facilities, both on-farm and in storage rooms.

2. The most important sub-systems in the country of the respondent scientist were, in decreasing order: primary production and food commodity processing, followed by animal production and fresh fruit distribution, as well as agro-industry goods distribution and commercialisation. Processed food distribution and industrial commodity processing appeared less important.

3. The ranking of crops by importance appeared heavily affected by the respondents' scientific interest, with some considering only field crops, others only fruit trees, both for fresh consumption (apple, pear, etc.) or for processing (olive, grapes), while a third group considered both sectors. The number and diversity of crops grown in different countries complicated the analysis of general trends. Grapefruit and banana were quoted as very important by scientists in the Canary Islands and cotton in Greece whereas barley and other small grains were prevalent in Northern Europe. Barley was considered from different perspectives in central–northern Europe and in the Mediterranean area.

4. The role of PGRFA in the country was assessed almost unanimously as important/very important for both plant and animal production, and for fresh food distribution and commodity processing. Public institutions are also interested in agro-industry.

5. Both local and introduced plant genetic resources were usually considered as important/very important. Countries' interdependence was considered high, and the importance of PGRFA was generally expected to increase or remain the same during the near future. The reasons for this continuing importance were: search of new traits, addressing the present narrow base in some crops, and need to increase biological resistance to disease and tolerance to environmental stress.

6. Most organisations have their own collections of PGRFA as seed or as living collections (fruit trees). Accessions were acquired as research material, finished cultivars, land races, and wild species; only a small part was acquired as genetic stocks or breeding material. Collections are used mainly for scientific research, pre-breeding and breeding, the main objectives for selected traits being tolerance to abiotic/resistance to biotic stresses and agronomic traits including yield, whereas nutritional and technological traits were considered as less important.

7. Exchange of genetic material occurs at least once a year in most organisations, with a range of species (1–5) and number of samples (10–200). Field collection, either directly or by external collectors, has also become quite

intense. The International Centres belonging to the CGIAR system are also relevant in supplying PGR, and the USDA continues to play an important role both for field and fruit tree crops.

8. Very rarely have organisations experienced problems with national authorities in obtaining access to PGR. Usually they did not attempt to ascertain whether the donor country had any law or regulation relevant to access and benefit sharing, and consequently they had no need to identify the authorities giving access to PGR. It was deemed unnecessary to take particular steps to ascertain whether collections complied with the appropriate legal requirements. This particular situation may be explained by the fact that a significant proportion of the exchange of material occurred within the EU, although non-EU countries, Asia, Northern, Central and Southern America, were also involved. The choice of the region was mainly dictated by the diversity harboured in those areas, the degree of similarity between the donor and recipient areas (aiming to gain access to adapted material), the presence of a gene bank, and common research interests with public organisations in the donor country.

9. Equally important was the supply, at least once or more a year, of small amounts of material to other organisations, usually in the EU but also in other continents. In this case most, but not all, organisations require a Material Transfer Agreement (MTA), but very few have established criteria and/or restrictions on whom to supply material.

10. Almost every respondent had heard about IT PGRFA (Appendix 3) and its provisions on access; however, little more than half of them felt that ITPGRFA '*would have effects on their own organisation*'. Some still consider PGRFA a heritage from the past, accessible to everybody, thus the ITPGRFA and state involvement is considered an increase in bureaucracy. Others recognised the need for a multiparty agreement, as a means for improving the organisation and use of PGR, better rules, easier access and benefit sharing. A third group anticipated difficulties in monitoring the current implementation of the ITPGRFA and monetary return, preferring the bilateral system.

11. Approximately half of the respondents indicated that new laws and regulations have been adopted in their countries to comply with the treaty provisions, although the majority (2:1) recognised that the ITPGRFA promoted a different country approach to exploration, conservation and sustainable use of PGR. They agreed that their countries have 'good' conservation facilities either *ex situ* or *in situ*, both on farms and in protected areas, and that they are providing good service in conservation and in providing material for research, although improvements are recommended.

12. The development of documentation systems on characterisation and maintenance of integrity of collections have been promoted by governments and local authorities, through new projects, including *in situ* conservation and encouraging sustainable use of PGR. This last goal is achieved by promoting the development of genetic diversity to reduce crop vulnerability, encouraging the use of under used crops, and strengthening the capacity to develop crops and varieties specifically adapted to local conditions. At the same time, authorities have adopted policies promoting the development and maintenance of diverse farming systems that enhance the sustainable use of agricultural systems through integrated pest management and by strengthening research on biological diversity conservation.

13. Authorities have also reviewed regulations concerning variety release, seed certification and quality control, have strengthened co-operation with other parties in the conservation and sustainable use of PGR, enhanced their international activities to promote conservation, to strengthen the capacity of developing countries in conserving and sustainably using their PGR, and have encouraged participation in activities promoted by the Member States, through networks and regional programmes. In addition, technical assistance was intensified by identifying, formulating and implementing projects, improving institutional capabilities, fostering regional and sub-regional co-operation.

14. On one of the most critical issues of the ITPGRFA, the PBR and farmers' rights, opinions were rather diverse, ranging from 'not known' to ' no action so far', from 'follow the International Convention for the Protection of New Varieties of Plants (UPOV) rules' to a 'matter for debate'. Access to material in gene banks by people from other countries should be decided 'case by case', 'only for scientific purposes', 'no access', 'yes with MTA'. Equally controversial was the direct use of plant genetic resources by farmers. At the current time, it seems that governments have not adopted provisions either for multipurpose crops, or for preventing recipients from claiming intellectual property (IP) or other rights that limit facilitated access to plant genetic resources or their genetic parts or components, in addition to MTA. Most respondents felt that PBR do not limit facilitated access to PGR; they interpret the sentence 'Recipients shall not claim any IP or other rights that limit the facilitated access to plant genetic resources or their genetic parts or components, in the form received from MS' as a prohibition to claim IP or other rights over the material in the form received, but PBR have to be 'granted for cultivars'. Also the

wording ‘in the form received’ is controversial: ‘a gene once isolated is not in the form received’ for some, it ‘is an integral part of the material’ for others, and the addition of a gene in a cultivar would produce a cultivar that may receive a plant variety protection under UPOV 91, but it is an ‘essentially derived variety’. It was not clear to most respondents whether MTA prevents material accessed from the Member State from leaking out of the system once in private hands.

All concurred that the Member State makes provisions for benefit sharing, through access and transfer of technology, exchange of information and capacity building, but they also contend that monetary and other benefits from commercialisation are difficult to secure, and collaboration is essential and urgent.

Appendix 3 Features of ITPGFRA

The objectives of the ITPGRFA are, *inter alia*, the following:

- to promote the development of national integrated approaches to conservation and use of PGRFA;
- to facilitate the access to plant genetic resources held by contracting parties and those in international collections.

To achieve these objectives the Treaty has established a special management system, under the direct control of the Governing Body (GB), composed of two main pillars:

- the multilateral system of access and benefit sharing;
- the benefit sharing fund under the funding strategy.

The multilateral system can be viewed as a worldwide global gene pool (currently some 1.2 million accessions of crops identified in Annex 1 of the Treaty) made available by:

- countries that are the contracting parties in the treaty;
- international organisations such as the International Atomic Energy Agency of the United Nations;
- natural and legal persons, such as private companies, which have begun to contribute breeding lines;
- other entities such as the International Agricultural Research Centres (IARCs) of the Consultative Group on International Agricultural Research (CGIAR), who currently make available some 600,000 accessions under the scheme.

The *modus operandi* designed by the Treaty foresees that once a system contributor (Provider 1) transfers, under the Standard Material Transfer Agreement (SMTA) – i.e. the standard contract containing several options designed by the GB – some material to a recipient, the latter also accepts the commitment to transfer the material to a second recipient exclusively under the same terms and conditions specified by the SMTA. The contractual chain thus established follows the material and builds obligations among providers and recipients. When the material eventually contributes to an invention or to the development of a patented commercial product, becoming the subject of a commercial benefit, the recipient has the obligation to pay 1.1% of the net sales of that product, for the patent life.

The funds so collected go to the second pillar, the benefit sharing fund, which is under the direct control of the GB and can be enriched by voluntary contributions by the contracting parties and/or other organisations. For example Norway, Spain, Italy and Switzerland have already made voluntary contributions. The fund is then disbursed to projects selected according to operational procedures and criteria established by the GB.

By endorsing the treaty, the contracting parties are committed to take measures to protect and promote farmers' rights, including the protection of traditional knowledge relevant to PGRFA, the right to participate equally in sharing the benefits arising from the use of PGRFA, and the right to participate in making decisions, at the national level, on matters related to the conservation and sustainable use of PGRFA. The treaty also specifies that nothing in the articles shall be interpreted so as to limit any rights that farmers have to save, use, exchange and sell farm-saved seed/propagating material, subject to national law. Some 30 countries have amended their seed legislation to accommodate the Treaty provisions. The EU is amending seed legislation to comply with this provision.

It is important to note that the ITPGRFA is the only fully operational, international Access and Benefit-sharing System for plant genetic resources. It reflects the needs of the agricultural sector and its specificity with respect to plant genetic resources policy, while providing an innovative instrument to address simultaneously several global challenges, such as genetic erosion and biodiversity loss, the rural poverty of small-holder farmers, the food crisis and the escalation of food prices, crop adaptation to climate change, and the bottom-up approach to development policy in agriculture. It has the potential to become a model for numerous other sectors, such as the World Health Organization (WHO), animal genetic resources and the United Nations Convention on the Law of the Sea (UNCLOS).

As the Treaty has moved from text to operational system, several technical and practical questions have been raised by users in day-to-day operations worldwide, which have been considered under the Agenda of the GB meetings or in that of other international organisations or agencies. Some examples of specific critical issues, which need to be solved, are indicated by Moore and Tymowski (2005) in their Explanatory Guide to the ITPGRFA.

Appendix 4 EU plant genetic resources collection and characterisation programmes

(1) Species included in the first plant genetic resources collection and characterisation programme (Hall, 2009)

Allium: Protecting future European Community crops: a programme to conserve, characterise, evaluate and collect *Allium* crops and wild species.

Avena: Evaluation and enhancement of *Avena* landrace collections for extensification of the genetic basis of *Avena* for quality and resistance breeding.

Barley: Evaluation and conservation of barley genetic resources to improve their accessibility to breeders in Europe.

Beta: Evaluation and enhancement of *Beta* collections for extensification of agricultural production.

Brassica: Collections for broadening agricultural use including characterising and using genetic variation in *Brassica carinata* for its exploitation as an oilseed crop

Carrot: The future of the European carrot – a programme to conserve, characterise, evaluate and collect carrot and wild relatives.

***Cucumis melo* (melon)**: Management, conservation and valorisation of genetic resources of *Cucumis melo* (melon) and wild relatives.

Eggplant: Genetic resources network – management conservation and valorisation of genetic resources of eggplants (*Solanum* species) – Eggnet.

Elms: Conservation, characterisation, collection and use of genetic resources of European elms.

Grapevine: European network for grapevine genetic resources conservation and characterisation.

Maize: Implementation of the European network for the evaluation, conservation and use of European maize landraces genetic resources.

Minor fruit tree species: Conservation, evaluation, exploitation and collection of minor fruit tree species.

Potato: genetic resources of potato, including conservation, characterisation and use of secondary potato varieties for ecological production systems in Europe.

Prunus: international network on *Prunus* genetic resources.

Rice (*Oryza sativa*): constitution, description and dynamic management of rice genetic resources.

Rosa: European network for characterisation and evaluation of genus *Rosa* germplasm.

In 2004 the EU became a contracting party of ITPGFRA and, with Council Regulation (EC) No 870/2004, established and co-funded with €10 million the Second Community Programme on the conservation, characterisation, collection and use of genetic resources in agriculture, comprising 17 actions, having the target of the following:

- promoting the *ex situ* and *in situ* conservation, characterisation, collection and use of genetic resources in agriculture;
- establishing a European decentralised, permanent and widely accessible web-based inventory of genetic resources currently conserved *in situ,* including *in situ*/on-farm genetic resources conservation activities;
- establishing a European decentralised, permanent and widely accessible web-based inventory of the *ex situ* collections (gene banks) and *in situ* facilities (resources) and databases currently available or being developed on the basis of national inventories;
- promoting regular exchanges of technical and scientific information, in particular on the origins and individual characteristics of available genetic resources, among competent organisations in the Member States.

(2) Species included in the second collection and characterisation programme (Hall, 2009)

Leafy vegetables: germplasm, stimulating use.

Management and conservation of **Grapevine** genetic resources.

Forest: genetic resources.

***Crocus* bank**: genetic resources of saffron and allies.

Genberry: European small berries genetics resources.

Eurigen: genotyping for the conservation and valorisation of European rice germplasm.

Euralliveg: vegetative *Allium*, Europe's core collection, safe and sound.

Aegro: an integrated european *in situ* management work plan: implementing genetic researves and on farm concepts.

Avena: genetic resources for quality in human consumption.

Cynares: genetic resources of *Cynara* spp.

Safenut: safeguard of hazelnuts and almond genetic resources: from traditional uses to novel agro-industrial opportunities.

Ribesco: core collection of northern European gene pool of *Ribes*.

The reforms of the Common Agricultural Policy (CAP) of June 2003 and April 2004 and the related Council Regulation (EC) No. 1698/2005, have offered opportunities at the national and regional level for financing the plant genetic resources preservation activities through Articles 39(1) to 39(4) and Article 27(4) of Regulation (EC) No 1974/2006: '*To preserve plant genetic resources naturally adapted to the local and regional conditions and under threat of genetic erosion*'; and through Article 39(5) of Council Regulation (EC) No1698/2005 and Article 28(3) of Regulation (EC) No 1974/2006: '*Operations at the national and regional level for specific support for the conservation of genetic resources in agriculture*', including the following:

- targeted actions: actions promoting the *ex situ* and *in situ* conservation, characterisation, collection and use of genetic resources in agriculture, including web-based inventories of genetic resources currently conserved *in situ*, including *in situ*/on-farm conservation, and of *ex situ* collections (gene banks) and databases;
- concerted actions: actions promoting the exchange of information for the conservation, characterisation, collection and use of genetic resources in Community agriculture, among competent organisations in the Member States;
- accompanying actions: information, dissemination and advisory actions involving non-governmental organisations and other relevant stakeholders, training courses and the preparation of technical reports.

In May 2006, the European Commission adopted a Communication on '*Halting Biodiversity Loss by 2010 – and Beyond: Sustaining ecosystem services for human well-being*'. The Communication underlined the importance of biodiversity protection as a pre-requisite for sustainable development; it recognised that biodiversity is not evenly spread and that much biodiversity resides outside the sites included in Natura 2000 and, by integration of biodiversity needs into agricultural policies, promoted a new biodiversity policy and plan, whose Roadmap included, *inter alia*: the afore-mentioned Council Regulation (EC) No 870/2004 which established the afore-mentioned second Community Programme on the conservation, characterisation, collection and use of genetic resources in agriculture;

In addition, there is a set of amendments to EU seed legislation to allow the marketing of conservation varieties:

- Commission Directive 2008/62/EC, allowing the registration and marketing of several landraces and varieties which are locally/regionally adapted and threatened by genetic erosion and that do not meet DUS criteria for marketing seeds;
- Commission Directive 2008/62/EC of 20 June 2008 providing for certain derogations for agricultural landraces and varieties threatened by genetic erosion and for the marketing of seed and seed potatoes of those landraces and varieties;
- Commission Directive 2009/145/EC providing for certain derogations, for vegetable landraces and varieties threatened by genetic erosion and vegetable varieties with no intrinsic value for commercial crop production;
- Commission Directive 2010/60/EU providing for certain derogations for marketing of fodder plant seed mixtures.

Appendix 5 Recent examples of research funded by the European Commission in relevant areas of biodiversity and international crop systems

(1) Examples of research funding in FP6 for biodiversity under the Environment research programme

EVOLTREE. Evolution of trees as drivers of terrestrial biodiversity.

2E-BCAS IN CROPS. Enhancement and exploitation of soil biocontrol agents for bio-constraint management in crops.

BIOEXPLOIT. Exploitation of natural plant biodiversity for the pesticide free production of food.

RHIBAC. Rhizobacteria for reduced fertiliser inputs in wheat.

MICRO-MAIZE. Management of plant-beneficial microbes to balance fertiliser inputs in maize monoculture.

(2) Research on underused crops in the FP6 International Cooperation Programme

CHERLA. Sustainable cherimoya production systems in Latin America.

INDIGENO. Sustainable production and marketing of indigenous vegetables through urban/peri-urban agriculture in sub-Saharan Africa.

PAVUC. Added value from underused tropical fruit crops with high commercial potential.

FONIO. Upgrading quality and competitiveness of fonio for improved livelihoods in West Africa.

BAMLINK. Molecular, environmental and nutritional evaluation of Bambara groundnut for food production in semi-arid Africa and India.

INNOVKAR. Tools and techniques for sustainable use of the shea tree in the Sudano-Sahelian zone.

MARAMA II. Development of innovative and healthful marama bean products targeting niche markets.

(3) Examples of research funding in FP7 for biodiversity under the Environment research programme

SOLIBAM. Increased understanding and use of Gene × Environment × Management interactions to improve crop breeding and production in highly variable organic and low-input systems. Crops: wheat, barley, maize, vegetables (including landraces).

PGR SECURE. Novel characterisation of crop wild relative (CWR) and landrace (LR) resources as a basis for crop breeding, and development of informatics. Genera: *Avena*, *Beta*, *Brassica*, *Medicago.*

FRUIT BREEDOMICS. Integrated approach for increasing breeding efficiency in fruit tree crops. Tree crops: apple, peach.

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Printed by Henry Ling Ltd, Dorchester, UK