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JRC SCIENTIFIC AND POLICY REPORTS

# Plant breeding for an EU bio-based economy

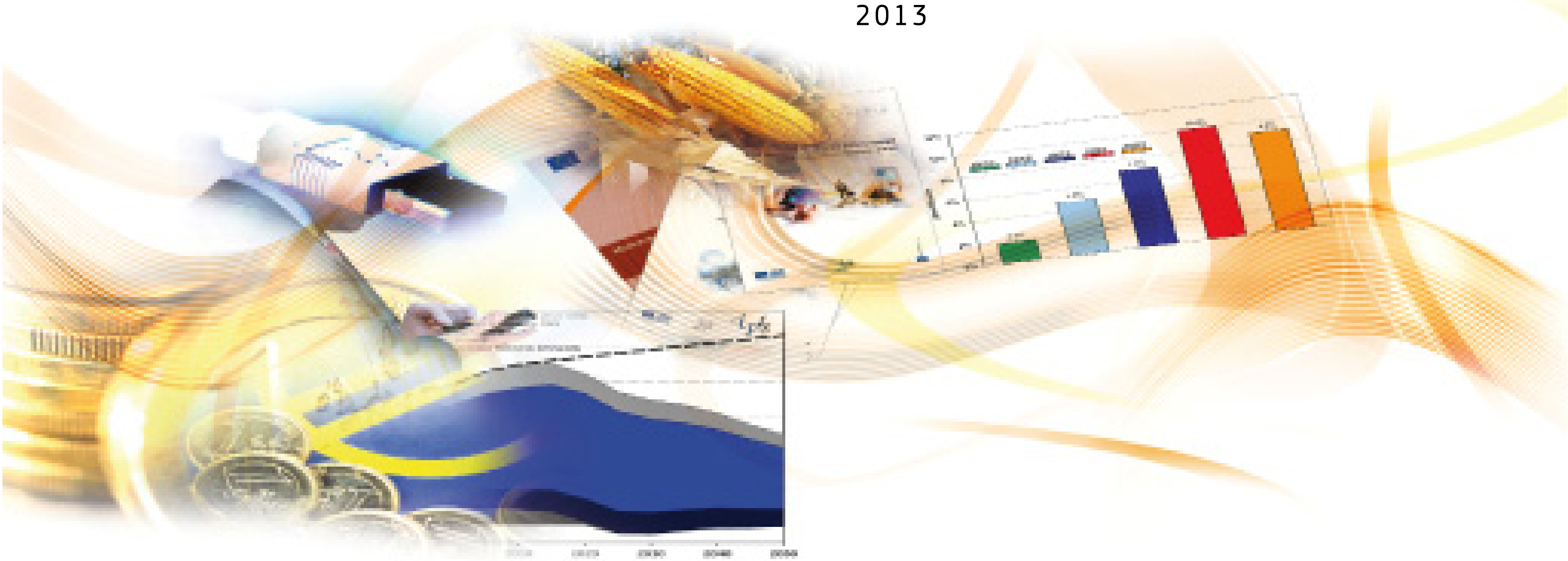
## The potential of public sector and public/private partnerships


Authors: Aad van Elsen, Alicia Ayerdi Gotor, Carmen di Vicente, Daniel Traon, Jacques Gennatas, Laurence Amat, Valeria Negri and Véronique Chable

Editor: Emilo Rodríguez Cerezo



2013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# Plant breeding for an EU bio-based economy

## The potential of public sector and public/private partnerships


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2013

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## Abbreviations

| | |
|---|---|
| **ACIAR** | Australian Centre for International Agricultural Research |
| **AEGIS** | A European Genebank Integrated System |
| **AFBI** | Agri-Food and Biosciences Institute |
| **AFLP** | Amplified fragment length polymorphism |
| **AGI** | Agricultural Genetics Institute |
| **ANR** | Agence Nationale de la Recherche |
| **AT** | Austria |
| **BBSRC** | Biotechnology and Biological Sciences Research Council (UK) |
| **BDP** | Bundesverband Deutscher Pfanzenzüchter (DE) |
| **BE** | Belgium |
| **BG** | Bulgaria |
| **BPH** | Brown plant hopper |
| **BSA** | Bundessortenamt (DE) |
| **CAP** | Common Agricultural Policy |
| **CC** | Common Catalogues |
| **CEFIC** | European chemical industry council |
| **CEI-BOIS** | The European Confederation of woodworking industries |
| **CEPI** | Confederation of European paper industries |
| **CGIAR** | Consultative Group on International Agricultural Research |
| **CIAA** | Confederation of the food and drink industry (recently renamed FoodDrinkEurope) |
| **CIMMYT** | International Maize and Wheat Improvement Center |
| **CIOPORA** | International Community of Asexually Reproduced Ornamental and Fruit Plants |
| **CIRAD** | Centre International de Recherche Agronomique pour le Développement |
| **CIRC** | Crop Improvement Research Club |
| **CLRRI** | Cuu Long Delta Rice Research Institute |
| **COPA-COGECA** | EU Farmers and Cooperatives Association |
| **CPVO** | Community Plant Variety Office |
| **CPVR** | Community Plant Variety Rights |
| **CSIRO** | The Commonwealth Scientific and Industrial Research Organisation (Australia) |
| **CY** | Cyprus |
| **CZ** | Czech Republic |
| **DE** | Germany |
| **DG RTD** | General Directorate for Research and Innovation of the European Commission |
| **DK** | Denmark |
| **DNA** | Deoxyribonucleic acid |
| **EBB** | European biodiesel board |
| **EC** | European Commission |
| **ECPGR** | European Cooperative Programme for Plant Genetic Resources |
| **EE** | Estonia |
| **EEIG** | European Economic Interest Grouping |

| | |
|---|---|
| **EMBRAPA** | Public agronomic research institute in Brazil |
| **ENZE** | Italian office in charge of variety registration |
| **EPR** | End Point Royalties |
| **EPSO** | European plant science organisation |
| **ES** | Spain |
| **ESA** | European Seed Association |
| **ETP** | European Technology Platform |
| **EU** | European Union |
| **EURISCO** | web-based catalogue that provides information about *ex situ* plant collections maintained in Europe |
| **FACCEJPI** | Joint Programming Initiative "Agriculture, Food Security and Climate Change" |
| **FAO** | Food and Agriculture Organization |
| **FCEC** | Food Chain Evaluation Consortium |
| **FCRI** | Field Crops Research Institute |
| **FERA** | The Food and Environment Research Agency |
| **FI** | Finland |
| **FP7** | Framework Programme |
| **FR** | France |
| **FTE** | Full Time Equivalent |
| **GEVES** | French office in charge of variety registration |
| **GFP** | Gemeinschaft zur Förderung der privaten deutschen Pflanzenzüchtung |
| **GHG** | Greenhouse gas |
| **GIPB** | Global partnership initiative for plant breeding capacity building |
| **GMO** | Genetically modified organism |
| **GR** | Greece |
| **GRDC** | Grains Research and Development Corporation of the Australian Government |
| **GxE** | Genotype x Environment Interactions |
| **ha** | hectare |
| **HU** | Hungary |
| **IAARD** | Agency for Agricultural Research and Development |
| **IBERS** | Institute of Biological, Environmental and Rural Sciences |
| **ICARDA** | International Center for Agricultural Research in the Dry Areas |
| **ICFORD** | Indonesian Center for Food Crops Research and Development |
| **ICRR** | Indonesian Center for Rice Research |
| **IE** | Ireland |
| **IHAR** | Plant Breeding and Acclimatization Institute (PL) |
| **INA PG** | Institut national agronomique - Paris Grignon (FR) |
| **INGER** | International Network for Genetic Evaluation of Rice |
| **INIA** | Instituto de Investigaciones Agropecuarias |
| **INRA** | Institut National de la Recherche Agronomique (FR) |
| **IPM** | Integrated Pest Management |
| **IPR** | Intellectual Property Right |
| **IPTS** | Institute for Prospective Technological Studies |
| **IRIWI** | International Research Initiative for Wheat Improvement |

| | |
|---|---|
| **IRRI** | International Rice Research Institute |
| **IT** | Italy |
| **JRC** | Joint Research Centre |
| **KBBE** | Knowledge Based Bio-Economy |
| **LT** | Lithuania |
| **LU** | Luxembourg |
| **LV** | Latvia |
| **MAS** | Marker assisted selection |
| **MS** | Member State |
| **MT** | Malta |
| **NAPB** | National Association of Plant Breeders |
| **NARDI** | See FUNDULEA |
| **NCPFT** | National Centre for Plant and Fertilizer Testing |
| **NGO** | Non-Governmental Organisation |
| **NL** | Netherlands |
| **NMS** | New Member State |
| **NSQCS** | National Seed Quality Control Services |
| **OECD** | Organisation for Economic Co-operation and Development |
| **PBCC** | Plant Breeding Coordinating Committee |
| **PBIC** | Plant Breeding Institute Cambridge (UK) |
| **PBR** | Plant breeders right |
| **PhilRice** | Philippine Rice Research Institute |
| **PL** | Poland |
| **PMP** | Plant-Made Pharmaceuticals |
| **PPB** | Participative plant breeding |
| **PPBM** | Public Private Business Models |
| **PPP** | Public/Private Partnership |
| **PT** | Portugal |
| **PVP** | Plant variety protection |
| **QA** | Quality assurance |
| **QMS** | Quality management system |
| **R&D** | Research and Development |
| **RFLP** | Restriction fragment length polymorphism |
| **RNA** | Ribonucleic acid |
| **RO** | Romania |
| **S&PM** | Seed and plant propagating material |
| **SE** | Sweden |
| **SEA** | South East Asia |
| **SeedNet** | National Rice Seed Production Network |
| **SI** | Slovenia |
| **SK** | Slovakia |
| **SME** | Small and medium enterprises |
| **SNP** | Single Nucleotide Polymorphisms |
| **SLU** | Swedish breeding institute |

| | |
|---|---|
| **TOR** | Terms of Reference |
| **UK** | United Kingdom |
| **UN** | United Nations |
| **UNIBO** | University of Bologna |
| **UPLB** | University of the Philippines Los Baños |
| **UPOV** | International Union for the Protection of New Varieties of Plants |
| **USA** | United States of America |
| **USDA** | United states department of agriculture |
| **VCU** | Value for Cultivation and Use |
| **WG** | Working Group |

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# EXECUTIVE SUMMARY

**Background**

The future standard of living (social and economic security) in the EU depends on its ability to drive innovation which, therefore, is a major focus of the Europe 2020 strategy.

In the field of bio-based economy, which covers exploitation of the full range of natural and renewable biological resources, agro biodiversity and biological material for food, in the form of bio-based products, the General Directorate for Research and Innovation of the European Commission (DG RTD) is currently developing an action plan called "*a Bioeconomy for Europe: Innovation and Sustainability*" in support of the EU 2020 strategy.

In that context, plant breeding provides important technical avenues, via the release of new varieties, to address the challenge faced by the bio-based economy sectors and to adapt to climate change. Moreover, it should continue to be a strong contributor to the enhancement of crop productivity, sustainability and the development of suitable crops for non-food use.

**Objectives and scope of the study**

The main objective of this study was to identify the relevant breeding needs for the bio-based economy in the EU by 2020 and to evaluate the extent to which these needs are currently covered by the private plant breeding sector. From there the study maps the past development and the present capacity of the public applied plant breeding sector. Eventually the study concludes on its potential to fulfil the breeding needs of the EU bio-based economy 2020.

The study covers the so-called conventional plant breeding sector encompassing breeding activities of germplasm characterisation and development, variety development, and variety testing. Genomic and pre-breeding activities do not fall under the scope of this research.

**Methods and materials**

The study covered a list of crops representative of the following groups: cereals (including wheat), oilseeds, pastures, fruits, vegetables, industrial crops, feed stocks for biofuel production, as well as grasses and trees, and feed stocks for chemicals and production of biomaterial.

The study process involved a combination of identification and data collection tools and included several phases:

1. An initial literature review and desk research to list breeding needs for the fulfilment of objectives of the EU 2020 bio-based economy (which needs for the strategy?).;
2. A large scale consultative exercise with plant breeders, plant scientists, producers, food supply chain actors, and policy makers through face-to-face and phone interviews for completing the list of plant breeding needs. This consultation included a workshop to validate the first findings of the research and to evaluate those breeding needs that are either currently not or insufficiently covered by the private sector ;
3. A second consultation exercise was done through a survey addressing past and current EU 27 MS public plant breeding resources and capacities ;
4. An additional literature review, completed by interviews, was carried out to compile an Endnote library. The review included major publications and scientific evidences addressing the evolution of the public plant breeding sector for the last 60 years ;

5. Last, conclusions were formulated after analysis of data taking into account the potential of the public plant breeding sector in the EU to meet the targets of the bio-based economy 2020 strategy.

**Breeding needs for the EU bioeconomy 2020**

Food consumption has steadily increased worldwide for decades and food demand looks set to continue its increase with an upward trajectory. Global population growth by 2050 is estimated to lead to demand a 70% increase which includes a projected rise in world meat consumption.

In parallel, the development of a global industrial system based on renewable plant-derived products as an alternative to the current system based on fossil fuel constitutes one of the most promising opportunities in terms of economic, social and societal potential.

These two objectives are increasingly competing for acreage as the global demand for food and industrial purposes develops over time. EU agriculture must also reflect on sustainability, thinking about mitigating measures and adapting to climate changes.

Agricultural research is meant to significantly contribute to address these challenges, and plant breeding is assumed to play a key role.

Crop productivity and sustainable production are mainly based on yield increase and yield stability, which remain the main objective of plant breeders for agricultural crops. Yield increase can be achieved by genetic gain as well as by using cultivars resistant to biotic stresses (plant diseases, pests, viruses and nematodes) and abiotic stresses (e.g. drought, cold, salt, metal). Breeding for biotic and abiotic stresses helps the sustainability of natural resources by reducing environmental footprints (e.g. less irrigation) and promotes a healthy and viable economy (e.g. less use of plant protection products and fertilisers).

Today, safety and quality of human food and animal feed are top priorities in Europe. The improvement of plants and the development of functional food ingredients contribute to high quality food. The first major goal is to produce food that is free of components that are toxic for humans. Such compounds can have a biological origin, such as mycotoxins, or an abiotic origin such as heavy metals or pesticide residues or other chemicals. Breeding efforts can achieve the reduction and elimination of toxic molecules such as glycoalkaloids, glucosinolates and trans-fatty acids from e.g. oilseed crops. The second objective is the development of tailor-made varieties with characteristics for the production of nutritionally enhanced food (vitamins, flavonoids and carotenoids).

Novel plant varieties shall provide solutions for the sustainable management of natural resources. New cultivars adapted to a range of stresses have improved yield stability and are more respectful with the environment. Crop productivity is increased while irrigation, salinization and dependence on plant protection products and fertilisers are reduced.

As animal protein consumption increases, understanding of animal nutrition together with breeding programs relying on modern technologies and approaches allow more efficient production and cause better feed composition (mainly energy content, protein content, and digestibility) while minimising the amount of grazing land, agricultural inputs, water or feed required.

When it relates to needs other than food (bio-energy and bio-chemicals), the classification of breeding needs is less evident than for human food and animal feed as these are new research areas not yet fully structured. However, literature shows that the scientific community considers that plant breeding is essential for setting up bio-based production chains. This is so because of the intrinsic properties of raw material and biomass that are decisive for its economic value and the sustainability of the production chain as a whole.

The development of diverse sectors by domestication of new crops, such as *Miscanthus, Jatropha, algae spp.*, provides opportunities for evaluating products as alternative sources of biomass and therefore reducing the demand on food crops. The forestry sector may also have great potential to produce a wide-range of innovative bio-products and biofuel raw material.

New plant materials may include medicines, specialty chemicals and enzymes, industrial feedstocks, polymers and fibres, produced either from conventional or genetically modified plants. Breeding new plants to produce specific pharmaceuticals may be seen as an efficient way of commercialising products such as vaccines for both human and animal care, even ii this research is at the proof of concept stages.

Other examples of biochemical production are specialty chemicals and enzymes (multiple opportunities ranging from surfactants and waxes for pigments to flavours and fragances) , plant-derived oils (lubricants, polymers, paints and solvents to inks, dyes, cosmetic products and surfactants), polymers (starch and rubber), and fibres (improvement of plant fibres via maize and poplar). None of these specific goals have led to significant achievements to date.

**Breeding needs not sufficiently covered by the private sector**

Private sector breeding is a confidential activity by nature meaning that it is extremely difficult to know the objectives of private breeders. It is also a commercial activity and therefore breeders' objectives are based on market demands and business opportunities, yield potential and yield stability of field crops partially reached by tolerance/resistance to biotic and abiotic stresses. In vegetables, breeders use qualitative criteria driven by the market demand.

In a large majority of crop species, the private sector seems to neglect the development of food and feed breeding programmes focusing on sustainability of carbon footprint, symbiotic relationship root bacteria-plants, and proof of concept research for orphan traits and minor crops.

Private sector breeding activities on bioenergy and biochemical-related targets could be boosted if there was heavy investment in public research. Today as the establishment of future markets and value chains is only partial, the seed industry seems to lack business opportunities to invest in breeding for these specific objectives. Breeding specific varieties for specific end-uses may entail changes in the process such as producing under contractual agreements that preserve the identity of productions.

**Potential and constraints of the applied public plant breeding sector (or public/private partnerships) to address breeding needs for the EU bio-based economy and climate change**

Plant breeding is considered one of the longest on-going activities undertaken by humans, who have selected more productive and useful plants from at least 10,000 years. The concept of plant breeding evolved based on the rediscovery of Mendel's laws in 1900 and the concept of natural selection by Darwin (1859) that provided the foundations for modern plant breeding. Since the end of World War II, the profile of a plant breeder has continued to change at a rapid pace. The main drivers of this evolution are the introduction of new technologies to speed-up breeding programmes and the possibility to protect and/or patent biological materials. These drivers led step by step and crop by crop to a shift of breeding activities from the public to the private sector.

In the EU, very few studies have been completed over the past 50 years to assess the privatisation of the public plant breeding sector. What is the number of public institutes/universities still involved in creating and releasing new cultivars? How many public breeders are active in the EU? Which crops are being bred by the public sector?

To answer these questions and to determine the past and current capacities and resources of the public applied plant breeding research in the EU 27 MS, a survey was conducted in the EU 27 MS during the summer 2012. The survey requested data starting in 2000 as the base year.

A complementary analysis addressing the evolution of public maintainers based on data from the EU common catalogues was carried out to validate (or not) the results of the survey.

A summary of the main findings of the survey is presented below. As explained, the term "plant breeding" used in the survey is restricted to activities of germplasm characterisation and development, variety development, and variety testing. Genomic and pre-breeding activities do not fall under the scope of the survey.

The main findings were:

- Crops and crop groups under public activities are mainly food and feed crops produced via the main grain commodity market. Very few initiatives are specifically targeting non-food and non-feed crops ;
- Plant breeding is multidisciplinary by nature. Public plant breeding concentrates on germplasm collection and characterisation and on variety development. In a large majority of cases, some variety testing is outsourced and marketing of varieties (production and sales) is assigned to a seed industry partner. Molecular breeding has been integrated in programmes as long as technologies can be used routinely ;
- Less than 1,000 staff has been inventoried in the public sector for conventional breeding activities of which the majority is located in the EU Eastern countries. In each of the main EU seed countries in Western Europe, staff is estimated at 50 FTE or less (a maximum of about 15% of the total breeding capacity). Evolution of the number of staff is MS specific and different profiles exist based on public policies for evolution of agricultural research ;
- Financial resources of the public sector are estimated at about 40 million Euros per year for developing new cultivars of which 31 million Euros come from IHAR in Poland alone. The private plant breeding budget is roughly estimated at 800-900 million Euros ;
- The number of varieties released by the public sector is negligible in comparison with the total number of varieties released per year by the private sector. In eastern countries, targeted traits are those agronomic traits that result in an optimal yield (economic) return for growers. In EU 15 MS, it appears that some institutes concentrate on working on other traits than those being worked for by the private sector. In all cases, the goal is mainly related to improving yield and yield stability associated with several abiotic, biotic and quality traits on a crop by crop basis ;
- With the definition of plant breeding used in the study (i.e. activities including up to variety testing and variety registration) it appears that in some member states no public sector institute could be identified as active.
- Public breeding resources come from public funding to the major exception of the NL in which the activity is based on a full cost recovery system. The importance of royalties seems to rise in the majority of cases. Very little resources come from contracting out of activities to either other public entities or private companies ;
- Public/private partnerships are more developed in the EU 15 MS than in the EU 12 MS, where public conventional plant breeders play the role of transferring technology to the market in collaboration with a commercial partner. The majority of these PPPs are dedicated to perform upstream activities (pre-breeding and genomics) ;
- Participatory plant breeding (PPB) is seen as an alternative to the current master scheme by a few research institutes and NGOs. In contrast, the seed industry does not see PPB as a viable alternative to the current system. The research study considers that the two schemes cover different agricultural

systems and do not compete with each other; on the contrary, they are complementary: PPB covers economic sectors in which seed companies have no interest ;

- Public maintainers in the EU 27 MS represent only about 7% of the total number of maintainers. The number of public maintainers decreases for field crops (- 7% since 2008) but is stable for vegetable crops.

**Public/private partnership in plant breeding**

Several public/private partnerships that have been recently initiated concentrate on pre-breeding but the general approach is to complete the R&D process up to the development of new cultivars in partnership with one or several seed companies. Therefore conventional breeding activities are developed in these programmes when progress is observed in the pre-breeding stage. This is for example the case of the BBSRC project in the UK. In 2005, 89% of government funding for plant genetic improvement was for basic research, and only 11% for applied breeding (mainly performed by private partners). A shift of funding might be observed when the first tangible results are released. This approach means that, when linked to fundamental research, public plant breeding funding increases and further PPPs may develop.

According to stakeholders from the plant breeding community and also highlighted by the Nordic Council of Ministers in its proposal to promote Nordic plant breeding, Plant breeding companies are prepared to collaborate with competitors in pre competitive research. Collaboration with public institutes is largely depending on the quality of the research of a public institute and how the intellectual property on the result of the research is shaped.

If excellence in research is given outside the EU, then companies will make use of it there.

**Conclusion on the potential of the EU public applied plant breeding sector to meet targets of the bio-based economy 2020 strategy.**

In light of the results presented above, the research team considers that it can hardly be envisaged that in the current conditions of resources and funding the public conventional plant breeding sector could deliver the new varieties with the traits required for fulfilling the needs of the EU bioeconomy strategy 2020, for which private plant breeding is not investing enough.

While the private plant breeding sector is concentrating on “cash crops” and is not investing enough on new varieties including traits required for fulfilling the needs of the EU bioeconomy strategy 2020, current public resources and capacities are too scarce to fully fill sectors not sufficiently covered by the private sector.

However the new models of public/private partnerships aiming at covering all R&D stages (from genomics to variety release) are a positive development as they will help targeting breeding of minor crops and developing new traits of interest for which business opportunities are not (yet) established: PPP to foster emergence of varieties that include new traits of interest.

# 1. INTRODUCTION

At the end of 2010 the process that started at the European Council in Lisbon in early 2000s and which was supposed to turn the European Union into the most competitive and dynamic knowledge-based economic area in the world has expired. In place of the Lisbon Strategy a new integrated growth and employment strategy called "Europe 2020 strategy" has commenced running until 2020.

The mere fact that the Lisbon Strategy is expiring is not sufficient reason for a new "EU 2020 Strategy". Rather the EU needs a new growth, employment and social strategy because the Lisbon Strategy was not capable of fulfilling the high expectations with regard to the benefits of Europe-wide economic and employment policy coordination and therefore failed on a number of essential points. At the same time new challenges have arisen for the EU and with the coming into force of the Lisbon Treaty the legal framework has also changed.

Europe 2020 is a ten year strategy proposed by the European Commission on 3 March 2010 for reviving the economy of the European Union. It aims at "smart, sustainable, inclusive growth" with greater coordination of national and European policies[1].

The Europe 2020 strategy[2] regards innovation as an effective approach for addressing societal challenges, such as climate change, energy and resource scarcity. In the field of bio-based economy[3] the European strategy and action plan, called "A bio-based economy for Europe: Innovation and sustainability" is being developed by the General Directorate for Research and Innovation of the European Commission (DG RTD).

In the field of agriculture, under the current review of the Common Agricultural Policy (CAP), the 2010 COM Communication[4] addresses the challenges of food security and climate change.

Eventually, the White Paper "Adapting to climate change"[5] establishes a European framework for action to improve Europe's resilience to climate change.

As part of these strategies a central role is envisaged for advances in plant breeding as it has already been the case during the green revolution[6]. Achievements of plant breeders are numerous and are not limited to yield increase. Breeding for plant compositional traits to enhance nutritional quality or to meet an industrial need are today major plant breeding goals (e.g. high protein crop varieties: high lysine or quality protein maize have been produced for use in various part of the world; different kinds of wheat are needed for different kinds of products such as for bread, pasta, cookies, semolina, etc…). Tremendous results have also been obtained in crop adaptation based on the so-called genotype by environment interaction approach (GxE)[7].

Plant breeding sector has been through several major restructuring and has turned to a recognised science in the 20th Century. In the early 1900s, much European plant breeding was supported by governments, and farmer cooperatives generally in charge of seed multiplication were frequent actors alongside a large number of mostly small private breeding firms. The supporting research in agronomy, plant pathology, entomology, biometry, plant

[1] "Europe 2020: Commission proposes new economic strategy", European Commission. Retrieved 5 March 2010

[2] Communication for the Commission to the European Parliament, the Council and the Committee of the Regions: Europe 2020 Flagship Initiative Innovation Union, SEC(2010) 1161.

[3] Bio-based economy covers the exploitation of the full range of natural and renewable biological resources, biodiversity and biological materials for bio-based products for use as food, as biofuel and in the industry

[4] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: "The CAP towards 2020: Meeting the food, natural resources and territorial challenges of the future", COM(2010)672.

[5] Commission staff working document « Adapting to climate change: the challenge for European agriculture and rural areas », COM(2009)147.

[6] Numerous studies have demonstrated that yield increase obtained by farmers could be attributed to genetic improvements of varieties to the level of a minimum of 50%. (e.g. Lucciani.2004.Etude du progress génétique chez différentes espèces de grandes cultures. GEVES Report. Slafer et al. 1994. Increases in grain yield in bread wheat from breeding and associated physiological changes. Genetic improvement of field crops. Book)

[7] E.g. Cooper et al., 1996. Plant adaptation and crop improvement. book. CAB International. Ceccarelli et al., 1994.Genotype by environment interaction and international breeding programmes. Experiment agriculture/Volume 3°/ issue 02

nutrition, plant physiology, and other cognate disciplines were also publicly financed. Improved varieties were freely released to producers at nominal costs that at best only partially recovered the costs of breeding, let alone making any contribution to funding the cost of supporting research.

Over time, the locus of plant breeding gradually shifted to the private sector, driven by the commercialisation of agriculture and the associated privatisation of agriculture research. Therefore, publicly funded agricultural research has been under concern for at least the last three to four decades. As a result, many public institutions have been under pressure to become at least partially self-funded, and have considered public/private partnerships as a possible long term funding option.

Too few analyses have been conducted to date to analyse the evolution of public resources engaged in plant breeding and to measure the actual applied public plant breeding capacities in the EU 27 MS. The main objective of this study is to close this data gap.

# 2. THE RESEARCH STUDY

## 2.1 Objectives

According to the ToR, the general objective of this study is to analyse the actual capacities of the public plant breeding area and its relation with the private sector (via public/private partnership - PPP) in order to fulfil the needs of the Europe 2020 strategy.

More specifically, the study shall focus on the following specific objectives:

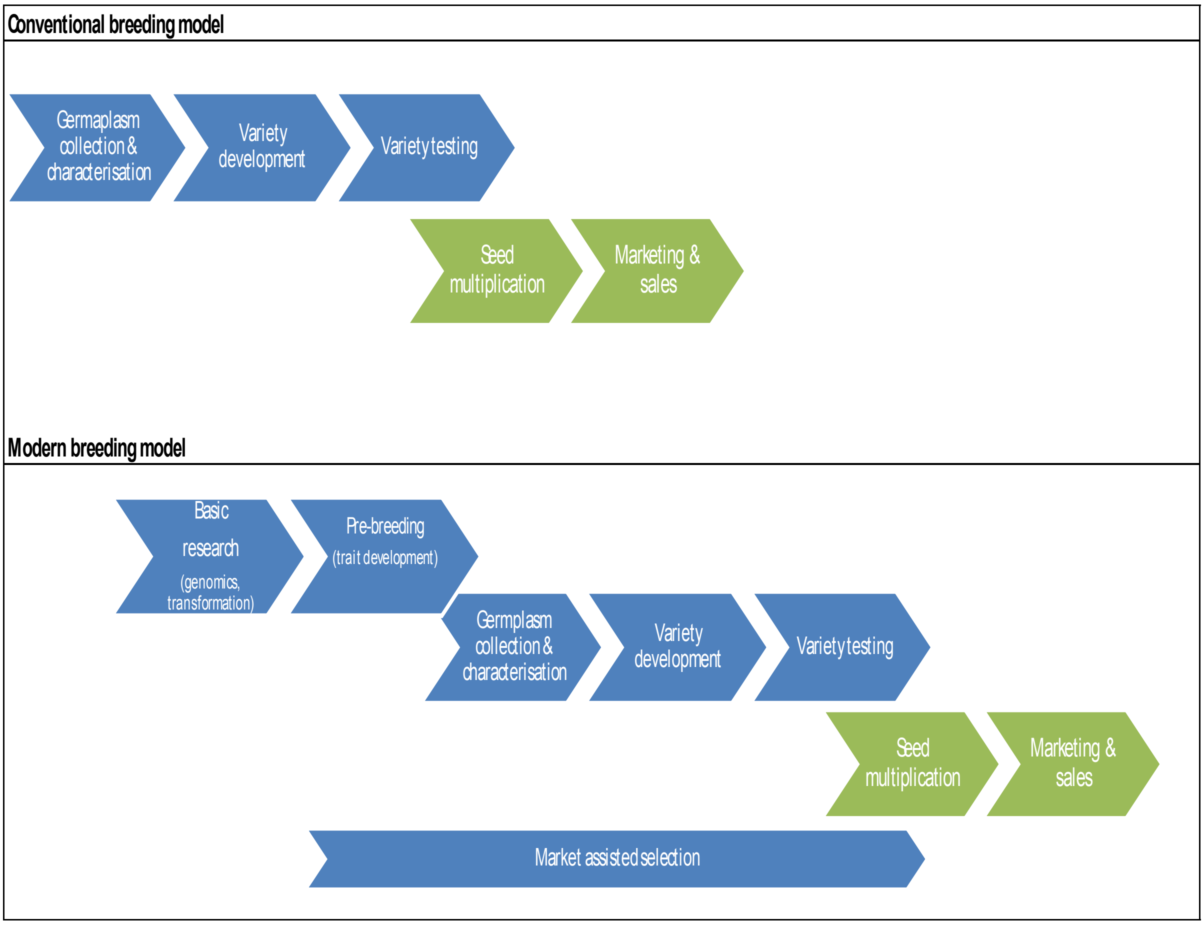
- To review main breeding needs for the EU bio-economy 2020 and climate change;
- To identify breeding needs for crop/trait combinations relevant for the EU bio-based economy and climate change that are currently covered insufficiently by the private EU sector;
- To review the structure and recent evolution of the public plant breeding sector in the EU;
- To analyse the potentials and constraints of the public breeding sector (or public/private partnership) to address these needs;
- Conclude on the potential of the public plant breeding sector in the EU to meet the needs of the bio-based economy 2020 strategy and climate change.

## 2.2 Scope

The analysis covers all EU 27 Member States. Member State information is being gathered through desk research, supplemented by surveys addressed to all MS and stakeholders across MS, and specific face to face and phone interviews. Serbia is also covered as historically it has had a strong public plant breeding sector and as it is a candidate for EU accession. To allow comparability of the evolution of the public plant breeding sector, a Third Country analysis has been performed via a qualitative assessment of individual public plant breeding capacities in Australia, Brazil, Chili, South East Asia (SEA), and the USA.

During the last 30 years, the plant breeding scheme which is crop specific has become more complex with the integration of new tools and new breeding techniques (e.g. molecular techniques, genetic engineering, genomics, etc…) leading to the situation that different breeding models can actually be distinguished. The following graph describes the two main breeding schemes: the so-called “conventional plant breeding scheme” and the “modern breeding scheme” in which molecular breeding methods have been integrated. These schemes are permanently being reviewed for process and cost optimisation. It is anticipated that it will continue to evolve over time with the development of additional added values techniques (enabling technologies).

**Figure 1 – The conventional versus the modern plant breeding model**




*Notes: in blue the breeding steps, in green the other seed business steps.*

The study covers the commercial breeding activities; the main focus of the research is on the applied/conventional breeding steps that are listed as follows:

- Germplasm collection & characterisation (including molecular breeding activities in support to germplasm characterisation;
- Variety development (mainly field nursery work); and
- Variety testing (multi-location field testing that takes place before registration of varieties).

Basic research and pre-breeding activities are not included in the scope of this study.

## 2.3 Crop coverage

The ToR of the study specifies that the crops covered shall be representative of the following groups: cereals (wheat included), oilseeds, pastures, fruits, vegetables, industrial crops, feed stocks for biofuel production, including grasses and trees, and feed stocks for chemicals and biomaterial production.

Based on discussions with experts and with the relevant EU Commission services (DG Research, DG SANCO, DG AGRI) during the structuring phase of the study, the following crops and crop species have been included in the scope of the research study.

**Table 1 - List of crops and crop species studied by the research[8]**

| Type | Group of crops | Crops |
|---|---|---|
| Food&Feed | Cereals | Winter wheat |
| | | Maize (silage and grain) |
| | | Triticale |
| | Oilseeds | Sunflower |
| | | Winter oil seed rape |
| | | Soybean |
| | Fodder plants | All gramineae |
| | | All legumes (focus on field pea) |
| | Vine | Vine |
| | Fruit | Apple |
| | Potatoes | Potatoes |
| | Vegetables | All Brassiceae |
| | | All lettuces |
| | | All tomatoes |
| | Industrial crops | Sugar beet |
| | | Hop |
| | | Cotton |
| Non-Food | Biofuel 1st generation | Maize |
| | | Oilseed rape |
| | Biofuel 2st generation | Miscanthus |
| | | Jatropha |
| | | Poplar |
| | Biomaterial | Maize |
| | Others | All |

## 2.4 Methodological approach (in brief[9])

The approach and the methodology deployed for the identification of breeding needs for the EU bio-economy 2020 and climate change and the analysis of the past and current public plant breeding capacities in the EU 27 MS has involved a combination of identification and data collection tools and included several phases:

- An initial literature review and desk research to list breeding needs in order to fulfil objectives of the EU 2020 bio-based economy (which needs for the strategy?). Results of this task have been compiled in an EndNote database listing the major scientific papers and other publications addressing future needs of the bio-based economy and presenting the possible role of breeding (public and private) to address these needs;
- A large scale consultative exercise with plant breeders, scientists, producers, food supply chain actors, and policy makers through face to face and phone interviews: This first round of interviews (55 in total) was initiated at the beginning of February 2012 and had the objective to complete the listing of plant breeding needs. This consultation process included a workshop that has been organised to validate the first findings of the research and to evaluate which breeding needs are currently not or insufficiently covered by the public sectors. This event brought together the EU plant breeding community from

[8] *The crop grouping is based on the actual structure of the Community acquis (marketing Directives) on the placing on the market of seed and plant propagating material in the EU – see* **http://ec.europa.eu/food/plant/plant_propagation_material/eu_marketing_requirements/index_en.htm**.

[9] The methodology is described in details in annexes

different sectors, as well as farmers and experts from the food and non-food supply chains, as well as EU policy makers. Forty one persons participated to the event, coming from 11 different MS countries. The workshop was structured in working groups to allow optimal participation of individual experts;

- A survey on past and current public plant breeding resources and capacities has been completed: The research team developed two survey questionnaires: the first survey (general survey) aimed at collecting information on conventional public plant breeding activities within the EU 27 MS; the second survey complements the first one as it targeted upstream R&D activities (pre-breeding). The survey was launched end of June 2012 and was carried out over the summer. The general survey was sent via Email to 281 representatives of the public sectors of 29 countries (EU 27 MS + Norway + Serbia) that received the General Survey questionnaire. The Specific Survey (which was optional) was launched via the EPSO secretariat that distributed the survey to all its members.

  In total the research team received 48 surveys from 21 countries, 12 completed specific surveys and 31 completed general surveys. Three EU MS indicated that no public plant breeding activities were occurring in their country any longer[10]. Therefore there was no need for them to fill the questionnaire.

- Follow-up interviews were conducted with selected respondents to the questionnaires for the purposes of clarification and analysis of specific responses and observations at greater depth in order to obtain an enhanced understanding of various aspects of the plant breeding needs (validation phase).

  The second consultation was conducted from August to October 2012, following the survey, in order to obtain complementary information.

- A second literature review, completed by interviews was carried out to compile an Endnote library including major publications and scientific evidences addressing evolution of the public plant breeding sector for the last 60 years. To this search, a Third Country analysis was completed to analyse evolution of public plant breeding capacities in several major agricultural countries in the world (Australia, Brazil, Chile, South East Asia, and the USA).

Several delays have been observed in answering to the general survey questionnaire as it was launched during summer time which is a very intensive labour period (field work) for breeders.

## 2.5 Structure of the report

After this general introduction presenting the background of the study, its objective and the methodological approach the report consists of two main parts.

- The first part (Chapter 3) lists the plant breeding needs required to fulfil the objectives of the EU 2020 strategy and summarises how these needs are considered (or not) by the private sector. A typology of needs is proposed and the likely breeding approaches and breeding prioritisation per crop/trait combination are also analysed;
- Chapter 4 maps the development of the EU public plant breeding sector (applied breeding resulting in cultivation of new varieties) in the past, current status and capacity of the public plant breeding sector (including public/private co-operations). This analysis is based on the results of the general survey as well as on the analysis of the evolution of public maintainers as listed in the agricultural and vegetables Common Catalogues. An introductory section describes the development of the public breeding sector in the EU since the end of World War II in comparison to the evolution of the private breeding sector in the EU and in the context of the global situation as well as a qualitative benchmarking analysis with Third Countries for a limited number of country/crop combinations. This chapter ends by a conclusion on the

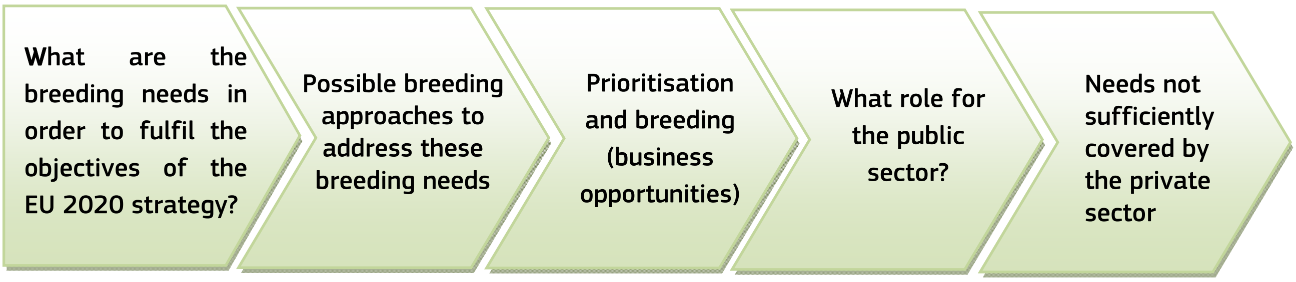
[10] In total, there is 8 MS in which public breeding do not occur (Information regarding the 5 others is based on information gathered from official authorities in charge of variety registration in neighbouring countries and based on the knowledge of the research study experts)

potential of the public plant breeding sector in fulfilling the needs of the EU sustainable bio-based economy until 2020.

# 3. TYPOLOGY OF BREEDING NEEDS FOR THE BIOECONOMY, PRIORITISATION AND ROLE OF THE PUBLIC AND PRIVATE SECTORS

This chapter presents the research conclusions related to the plant breeding needs required to fulfil the objectives of the EU 2020 strategy and summarises how these needs are considered (or not) by the private sector. The likely breeding approaches and breeding prioritisation per crop/trait combination are also analysed.

**Figure 2 – From breeding needs to public and private plant breeding roles**




When analysing the conclusions of this section, it is important to remind that more criteria (e.g. geographic priorities, freedom to operate, regulatory burdens) should be considered to draft a more detailed analysis on the respective role of the public and private sectors. These additional criteria should be applied on a crop by crop basis.

Additionally results that are presented in this study are quite general and based on experts opinions rather than on hard data.

## 3.1 What are the breeding needs in order to fulfil the objectives of the EU 2020 strategy?

Under this chapter the list of breeding needs to fulfil the objectives of the EU 2020 strategy and the long-term needs on the bio-based economy are presented and are illustrated by business opportunities examples.

The production of food and feed remains the primary objective of plant science and especially of plant breeding (ESA, 2012). Over the past 50 years, improvements in knowledge of plant genetics, physiology and agronomy have underpinned the large increases in crop productivity (Dethier & Effenberger, 2012; Duvick, 2005; Pray, 2007; Reynolds, 2012).

For the last two decades new challenges are arising and plant breeders have to pursue a number of additional objectives (Chakraborty, 2011) not only leading to food security but also oriented to food safety, food quality (Choo, 2010; Duvick, 2001; Zanetti, 2009), the respect of the environment; and developing crops that are resilient to climate change (Ceccarelli, 2010; Lobell, 2008; Luck, 2011; Reynolds, 2010; Shyam-Singh, 2011).

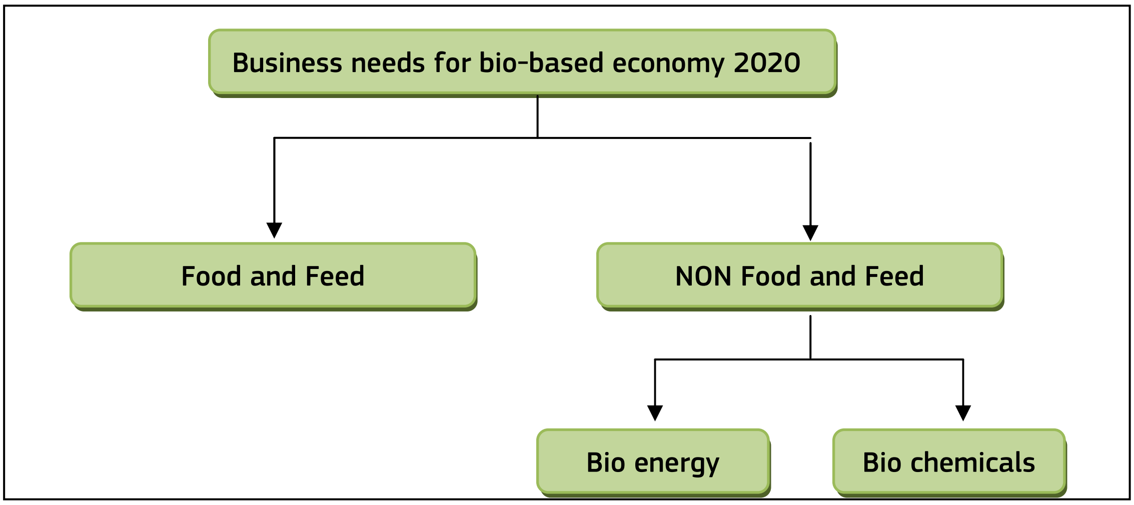
Interviewees met during the research study clearly mentioned that the main plant breeding objectives will remain agronomic traits that lead to high yield and high quality. Farmers have to be guaranteed that the variety will yield enough to secure a correct economic return. Other traits (e.g. product composition) are coming additionally to regular agronomic traits.

By 2020, 20% of transport fuel should be derived from biomass, according to the EU biofuels Directive. The key technological challenges for the production of renewable biomass-based fuels require a high degree of optimisation of the cost-efficiency of biofuel production, including biomass yield, nutrient and water use efficiency, and energy conversion efficiency. Several authors have highlighted that agricultural feedstock can play an important role for bioenergy production (Annevelink, 2006; Carlsson, 2011; Hood, 2011; Ree, 2007; Séguin, 2011).

Additionally plant breeding can help converting plants into green factories for the production of chemicals (Annevelink, 2006; Carlsson, 2009; Howard, 2005; IPBE, 2011; Mascia, 2004). According to European technological platform "Plant for Future"[11], the development of the knowledge-based bio-economy – involving a global industrial system, producing chemicals, based on renewable plant-derived products as an alternative to the current fossil fuel-based system – constitutes by far the most challenging and promising opportunity in terms of economic, environmental and societal potential.

Vanek indicates that bio-refineries are using about 5% of bulk raw materials from plants in the form of wood, carbohydrates, oil, fibre and protein. The major part comes from fossil fuels and natural gas (Vanek, 2010). By 2025, 30% of the raw material needed for chemical manufacture in the EU could be obtained from plant-derived renewable resources (Royal Society of Bangor University, 2009).

**Figure 3 - Business needs classification**




*Source: Compiled by Arcadia International*

### 3.1.1 Food and Feed

Since World War II, plant breeding has been associated with the idea of producing more food in order to secure food security. Productivity has been the major driver and the EU regulatory framework related to the marketing of new cultivars, that dates back to the 1960s, is including criteria for registration related to yield and crop productivity which have been integrated in the value for cultivation (VCU) approach (FCEC, 2011).

During the last ten years, it can be observed that national authorities have slightly modified criteria for the registration of new varieties on national catalogues in order to answer to new challenges of agriculture (food safety and respect to the environment) by giving more importance to traits such as disease resistances, product composition, oil profile for oilseeds crops, etc… (FCEC, 2011).

Indeed, the production of healthy, safe, nutritious food and feed is dependent on complementarity between two industrial sectors that have traditionally been largely independent, the seed industry and the food industry. The 2006 survey on Future Plant Research Activities in Europe performed by the European Technology Platform (ETP) highlights that the seed industry has largely focused on the improvement of commodity crops such as wheat, other cereals, oilseeds, and maize and some vegetables. In cases the food industry requires additional specialty

[11] Plants for Future http://www.epsoweb.org/Catalog/TP/

crops e.g. waxy and sweet maize, sugar beet, durum wheat, niche markets have been created based on a limited number of breeding companies that have invested in developing specific varieties to fulfil the needs of these niche markets (European Technology Platform, 2006).

There is a growing interest of consumers and food processing companies to focus on quality products that are healthier and that have improved sensorial characteristics. Therefore, these industries have asked plant breeders to develop specific cultivars to address these objectives. They are requesting that breeders develop new varieties leading to raw materials that are better adapted to the production of particular foodstuffs.

The above mentioned ETP survey of the research community revealed a clear readiness to address these new needs. The new plant breeding techniques have helped advancing in the understanding of plant biology based largely on research performed in *Arabidopsis*[12]. Molecular breeding, which is today largely used, is helping plant breeders to characterise their germplasm and to identify alleles of interest for a specific trait. The ETP survey results also highlight the FP7 projects that have addressed these needs but do not conclude on the extent to which plant breeders have integrated these new needs as objectives in their breeding programs).

**In contradiction to these new approaches, private plant breeders that have been met during the course of this research study, have mentioned that breeders are investigating on these new traits (e.g. healthier and improved sensorial characteristics but that in a large number of cases these breeding efforts remain marginal to date.**

For the purpose of this study, the research team has analysed several classifications available in the literature of plant breeding approaches related to food and feed needs. This preliminary analysis has been completed by a literature review and experts' interviews and the final classification has been validated with experts present at the workshop that took place in the course of this study.

It is proposed to group the food and feed breeding needs in four themes as follows:

- Food security: develop and produce sufficient, diversified and cost affordable high-quality plant raw materials for food and feed products;
- Food health and safety: produce safe food products and tailor made plant raw material for certain health benefits and specific consumers groups;
- Respect of the environment;
- Feed security and safety.

## Food security

Plant breeders' top priority has traditionally gone to productivity[13] and affordability[14] (Duvik, 1986; Frey, 1971). In the last 3-4 decades, more focus has been put on the quality of the harvested raw material (enhancement of compositional traits) and on crop adaptation (genotype x environment interactions) (An Najah University, 2000).

**However, productivity remains the most important objective of breeding agricultural crops as food demand continues its upward trajectory due to population growth and improving living standards across the globe**[15].

Productivity as related to sustainable yield increase, can be approached by breeders from complementary angles:

[12] In the last two decades, *Arabidopsis thaliana* has gained much interest from the scientific community as a model organism for research on numerous aspects of plant biology.

[13] Productivity has to be understood as quantitative (yield) when it refers to agricultural crops and mainly qualitative for vegetable, ornamentals crops.

[14] Affordability: possibility to breed new varieties at a reasonable cost.

[15] Conclusion by authors based on experts interviews

- Yield improvement: yield increase based on higher yielding varieties (genetic yield improvement) and more stable varieties (yield stability)[16];
- Yield increase via improved varieties resistant to biotic stress (Noack, 2003; Stuthman, 2007):
    - Virus resistance: several crops (e.g. fruit crops, potatoes), whose damage by viruses have important economic consequences,, are the targets of specific breeding programs aiming at creating resistant cultivars;
    - Fungal pathogens: they are recognised as major sources of losses in cropping systems; they also produce toxins and thus compromise food safety. To date, plant breeders have developed resistant varieties to diseases via conventional breeding. It can be considered that in crops where diseases are of key importance, breeding objectives target resistant varieties;
    - Insect resistance: insects induce important losses in the majority of crops if no chemical protection is being applied (insecticides). Breeders' objectives are also addressed to find resistant cultivars. So far most of the efforts have been done via conventional breeding. Current outcomes are rather limited.
    - Nematode and bacterial resistance is a breeding objective in a limited number of crops (some vegetables and potatoes);
- Yield increase via improved cultivars with better nutrient uptake capacity from fertilizers in the soil (Abberton, 2010; Ortiz-Monasterio, 2007; Pfeiffer, 2008); and
- Yield stability under stress conditions (abiotic stress criteria):
    - Salt stress: Intensive soil irrigation often leads to salt accumulation and to yield losses. The problem increased as an indirect consequence of climate change. Breeders may help overcoming this issue by mining genetic diversity of crops to improve their tolerance to salts ;
    - Cold stress ;
    - Drought stress: Drought is certainly the major abiotic factor affecting yield with an increasing importance with climatic changes (Sadok, 2011). The issue is subject to high investment by both the private and public plant breeding sectors;
    - Metal stress: Tolerance against toxic metals (heavy metals) is essential for plant production as accumulation of these heavy metals is observed in most fields in Western Europe. Reducing heavy metal contamination in food products is today recognised as an emerging problem, therefore tolerant varieties are needed as well as plant varieties to be used in phytoremediation processes.

A cross-cutting criterion in relation to food security is the need to develop and produce diversified raw materials. Whether it is for fresh or processed foods, consumers expect diversity in terms of taste, nutrition, and convenience. This is translated into an increase expectation of different raw materials and ingredients in the supply chain to fulfil the variability of the demand. Therefore it is important to maintain a high level of diversity for different crops.

## **Food safety and food quality**

Food safety and food quality address two different complementary needs:

- Reduction of possible food threats in crops and raw materials: A major goal is to produce food which is free of components that are toxic for humans. Such compounds can be of biological origin, such as

[16] For further information on yield stability vs yield improvement, see Pfeiffer et al. Enhancing genetic grain yield potential and yield stability in durum wheat available at http://ressources.ciheam.org/om/pdf/a40/00600009.pdf

mycotoxins, or of abiotic origin such as heavy metals, pesticide residues or other chemicals. The concern of presence of heavy metals in food products has already been highlighted above; a second example of food contamination is the presence of highly concentrated mycotoxins in cereals. Mycotoxins are currently growing concerns for the food and feed industry because there are more and more difficulties in meeting European regulation standards for mycotoxin contamination. Breeding efforts addressing this issue by developing *Fusarium* resistant/tolerant plants may address this issue (Lehoczki-Krsjak, 2010). A third example in this area is the breeding effort to reduce and eliminate toxic molecules such as glycoalkaloids, glucosinolates and trans-fatty acids from e.g. oilseed crops (Bouis, 2003).

- Nutritional quality: development of tailored made varieties with improved characteristics to produce nutritionally enhanced food (healthy food): in these cases breeding aims at increasing the presence of plant compounds that are beneficial for human health, that is enriching and optimizing such compounds that are linked to health benefits (for example food enriched with vitamins, flavonoids and carotenoids) (Bouis, 2003).

## Respect of the environment

Several new plant breeding approaches related to plant stress as described above are primarily taken to secure an optimal economic return of a given crop for the farmers. This means that any phenomenon potentially affecting the return level in terms of yield decrease and/or quality reduction will be considered by breeders.

For example, when a breeder selects cultivars that are more resistant to diseases, his objective is to secure that these diseases will not damage the crop and therefore its yield potential is guaranteed.

As a secondary benefit, breeding to avoid plant stress may prove to be beneficial for the respect of the environment and in several domains.

When a plant breeder launches a new breeding program on disease resistance, he/she will first focus research on diseases for which a crop protection chemical solution does not exist. For example, there is very little interest in breeding for wheat varieties resistant to *Septoria spp* as there are numerous plant protection products available on the market. Farmers are used to apply fungicides, therefore they would not see an advantage in buying resistant varieties for that specific disease. When it relates to diseases for which chemical solutions do not exist, the situation changes, and plant breeding efforts will commit to this type of diseases (e.g. club root in oilseed rape).

Therefore, the actual plant breeding efforts to develop new cultivars resistant to diseases have a limited impact on the use of PPP (reduction of volume). However the new EU policy on sustainable use of pesticides (Framework Directive 2009/128/EC) intends to promote Integrated Pest Management (IPM) approaches and therefore it is supposed to be an incentive to further develop resistant varieties in order to reduce volumes of PPP applied in farmers' field. In this context plant breeding efforts releasing resistant varieties for the most common diseases will lead to reduction of use of PPP and then to a positive move forward for the respect of the environment. Several countries (e.g. France, Germany)[17] have recently launched public research projects in that direction.

The current approach related to nutritional stress is comparable as the identification of adaptive traits involved in the response of plants to nutritional stress is necessary for maintaining crop productivity at sustainable levels. About 50% of cultivated soils are subject to nutritional stress (An Najah University, 2010) and in order to respond to this problem, intensive fertilisation in developed countries has increased environmental pollution. Cultivation of plants that more efficiently absorb and utilise the nutrients could reduce the use of fertilisers, input costs and loss of nutrients to ecosystems (leaching). Nutrient uptake efficiency is known to be under genetic and physiological control and may be a useful genetic trait for adaptation to lower soil nutrient conditions. Plant factors influencing nutrient uptake are mainly associated with root characteristics which are very criteria that are difficult in a regular breeding program.

[17] See http://www.endure-network.eu/

The growing knowledge of the factors important for phytoremediation can provide a basis for genetic modification of plants for improved performance. Breeders have been modifying agronomical traits for years. However, phytoremediation requires a new paradigm in which plants are valued based on what they absorb, sequester, destroy, and tolerate. For example, there have been many attempts to breed willow, poplar and other plants with properties useful for phytoremediation. The aim is to develop plants combining the high ability to accumulate, detoxify or degrade xenobiotics and pollutants, with resistance to the toxic compounds present and with suitable agronomic characteristics (Macek, 2002). Traditional breeding and molecular biology can specifically target all of these traits but in reality commercial breeders have achieved very little progress in this area. Plant biotechnology and genetic engineering are therefore considered to be the best approaches to fulfil these objectives. Interesting papers on genetically engineered plants, suitable for metal accumulation, have recently appeared, indicating the growing interest in the application of biotechnology to the phytoremediation of inorganic compounds (Clement, 2002; Pilon-Smith, 2002). Several traits of plant root structure could be improved. These include root depth, penetration into anaerobic zones, and root density. Deeper roots would increase the depth from which a contaminant could be retrieved for phytoremediation.

#### **Feed security and feed safety**

Literature shows that when breeding needs for food production are well defined, few papers discussed the specific breeding needs for feed. Plant breeding history shows that the main approach to breed dedicated varieties for feed is to start from the breeding for food approaches. **Advances in plant breeding techniques by using molecular breeding techniques could help improving feed composition (mainly energy content, protein content, and digestibility), while reducing costs.**

When it relates to digestibility and energy content, the major examples in this field are silage maize which can be considered as a success story, contrary to field peas which have nearly disappeared from the farmers' field for the last 20 years.

Pea is a source of protein both for human food and animal feed. Pea is the most widely grown grain legume in Europe as it represents a versatile and inexpensive protein source for animal and can be a substitute to GM soybean meal imported from South America. Significant efforts have been made in pea breeding for yield and disease resistance in the past. However, yield stability is one of the issues that has never been solved by breeders resulting into years with excellent yield and good return to farmers combined with years with poor yield (Monti, 2006). This lack of yield stability led farmers and commercial breeders to abandon this crop. Public plant breeding efforts have also been reduced. Nearly no breeding activities are currently on going to the exception of several former Eastern countries (CZ, PL).

**These two examples show the importance of public plant breeding in the development of private breeding efforts. In silage maize, the public breeders helped initiating the development of that "market"; in field peas, the lack of public support has caused the near disappearance of this crop in the EU.**

### *3.1.2 Non-food – bio energy*

When it relates to non-food needs (bio-energy and bio-chemicals), the classification of breeding needs is less obvious than for food as we are in new research areas not fully structured yet.

Regarding bio-energy, the transition from our current fossil fuel-based industries to bio-based industries already has far reaching and great effects on agriculture. For example, the US corn production is today dedicated more for ethanol production than for food production (USDA statistics, yearly publications). This phenomenon is not so pronounced in the EU to date.

This transition will require considerable investments in research of feedstock production, conversion processes and large-scale capital infrastructure. In essence and in addition to the contribution of forestry to bio-energy, it was envisaged that agricultural raw materials might become feedstock for the production of bio-energy and biofuels. The food crisis of 2007-2008 has highlighted the current competition that exists between food and feed raw material *vs.* agricultural raw materials for biofuels production (European Parliament, 2008). As the first generation of biofuel and bioethanol production was based on oilseed rape and maize, respectively, the second generation of bio-energy is targeted to non-agricultural species and other sources of biomass (waste recycling).

Koops and Trindade (2010) present a clear and complete vision of the plant breeding objectives in relation to the bio-based production chains (bioenergy and biochemical). More particularly, the authors highlight that plant breeding is essential in setting up bio-based production chains because the intrinsic properties of raw material and biomass are determinative of its economic value and the sustainability of the production chain as a whole.

They add that until now, the development of many bio-based products started at the end of existing production chains by using biomass derived commodities e.g. sugar, oil, glycerol and starch and insists on the fact that further improvements are strongly dependent on the properties of plant propagation material that can be improved via breeding (Koops, 2010).

The first generation of biomass fuels, that are currently produced, are derived from special biomass feedstocks that are efficiently converted into biofuels as transportation fuels. These feedstocks are either sugar or starches which are fermented into bio-ethanol or vegetable oils that are often converted into biodiesel.

## Energy net balance optimisation in common grown crops

**This first generation biofuel crops are in fact food and feed crops which have been optimised for food and feed production, but not for biofuels**. Hence, neither the biomass yield nor the input requirements are optimal. Furthermore, the net energy balance – i.e. the ratio of output to input energy – of these first generation biofuels is far from ideal. European plant breeders are clearly mentioning that no significant efforts are currently devoted to breed varieties adapted for these uses as needs were not clearly defined by the downstream chemical industry.

The second generation biofuel crop species – dedicated energy crops – will be tailored specifically to the production of biofuels with **optimised biomass yield** (Loyce et al., 2012; Oliver, 2009; Schutter, 2011; Séguin, 2011). It is generally envisaged that these second generation energy crops will produce primarily lignocellulosic feedstocks that will be fermented into bio-ethanol using novel saccharification and fermentation technologies.

## Domestication of new crops

Additionally, **dedicated and novel energy crops are considered as alternative approaches to avoid competition with food and feed production** (European Parliament, 2008). Perennial grasses show many beneficial properties as energy crops, and have been evaluated as bio-energy feedstocks in both the US and the EU.

A large number of perennial grasses have been grown or tested as energy crops in Europe. Research mainly focused on four species: reed canary grass, *Miscanthus sp*, switchgrass and giant reed. These energy crops can be harvested in late autumn to early spring, when nutrients are stored in the rhizomes. The annual biomass yields reported range from 5 to 40 tonnes of dry matters per hectare and per year.

***Miscanthus sp as a bio refinery crop.***
***EU potential acreage: 1 million ha.***

*Miscanthus sp* is a perennial crop with a very high biomass yield and is the most close relative to sugar cane. This giant grass is considered as one of the best lignocellulose crops for bio-energy applications in view of the low production costs, low nutrient consumption, the capacity to fix atmospheric N, and a high net energy yield. The business concept for *Miscanthus* includes the development of a refinery crop that can be harvested once or twice a year, the first (green) harvest for protein and sugar production, the second harvest for lignocellulose biomass production.

The main breeding challenges are:

- Development of a diploid genotype that can be reproduced via seed;
- Improvement of the cell wall composition to reduce the energy costs for recovery and to improve the fermentability of the lignocellulose biomass;
- Improve *Miscanthus sp* biomass quality for biomaterials and biochemical.
- Increasing protein content and improvement protein quality;
- Development of a crop with a very high fermentable sugar content by crossing *Miscanthus* with the genetically closely related sugar cane

*Source: Wageningen University*

Other crops are subject to consideration for bio energy oil production. Most of these are tropical crops the main example of which is *Jatropha curcas*. Interest in *Jatropha curcas* as a source of oil for producing biodiesel has arisen as a consequence of its perceived ability to grow in semi-arid regions with low nutrient requirements and little care. The seed typically contains 35 percent oil which has properties highly suited to making biodiesel. Jatropha' main weaknesses relate to the fact that it is an essentially wild plant that has undergone little crop improvement. Knowledge of the agronomy of jatropha and how agronomic practices contribute to yield is generally lacking. Several breeding programs have been initiated by petroleum companies about 5 years ago. If the first results are already being seen (detoxification of the meal cake used as feed); the major outcomes of these breeding programmes may not be seen before several years (Jongschaap, 2010).

Additional crops/organisms have been identified e.g. starch potato, non-food oil crops, *Calendula sp, Crambe sp*, natural rubber crop such as Russian dandelion and Guayule, and algae as potential feedstocks for bio energy production, but crop improvement research efforts seem to be marginal at this stage[18].

For most of the experts that have been interviewed during the research process, high-energy crops will most likely be based on the application of plant biotechnology and molecular breeding techniques in order to speed up the breeding process for a quicker delivery of superior cultivars.

### *3.1.3 Non-food – bio chemicals*

It is a clear objective of the EU bio-based economy to increase the percentage of plant derived renewable resources used for synthesis of biochemical and biomaterials. Today only about 5% of the actual EU industrial raw material volume is based on bulk materials from plants (wood, carbohydrates, oil, fibre, and protein) (ETP, 2006).

[18] Conclusion by authors based on experts interviews Conclusion by authors based on experts interviews

***Beet as production platform for bulk chemical & industrial sugar.***
*EU potential acreage: 750 000 ha, corresponding to the decline in EU sugar beet acreage since sugar reform 2006*

Besides potato, beet is the only other Northwest European refinery crop. Yield is very high and beet is as such competitive with sugar cane, one of the world's highest yielding crops. According to a number of chemical companies, beet and cane are obvious crops as source of raw materials for chemical industry, including chemical raw materials and cheap industrial sugar. To increase cost competitiveness and added value of the beet production chain, the main research challenges (including breeding) include:

- Reduction of the cultivation costs by increasing N use efficiency.
- Improvement winter hardiness. These beets could be harvested during winter, thus permitting the use of existing factory capacity (already now used for crystal sugar production, but only during 65 months) for processing extra biomass the chemical market in existing factories. This will result in a drastic reduction of the capital costs of sugar factories per ton of processed sugar beet.
- Other processing methods enabling complete conversion of all remaining biomass into bioPET and other biopolymers
- Introduction of the ability to produce high value bulk chemicals up to a level of about 10% of dry weight.

*Source: Wageningen University*

New plant raw materials may include medicines, specialty chemicals and enzymes, industrial feedstocks, polymers and fibres, produced either from conventional or genetically modified plants. Biotechnology is certainly the preferred approach and will be used for concept proofing. However, these markets are currently niche markets and costs to deliver cultivars to produce these chemicals are not affordable for business cases where these niche markets are not large enough.

***Oil crops as source of oil-based chemicals and protein. EU potential acreage: two crops on 50 000 ha each.***

Most seed oil crops for use in food contain the "standard" C16 and C18 fatty acids. This is the reason why currently only 10% of all plant oil is used for chemical applications.
A number of oil crops, e.g. *Calendula* and *Crambe* contain special fatty acids of which 100% can be utilised in industrial products with high added value. *Calendula* oil is very suitable for use as reactive solvent in low-solvent alkyd paints and as wood preservative. *Crambe* oil, with high content of erucic acid, is an excellent raw material for erucamide, an additive for plastics. *Crambe* is also very suitable as production platform for various new oil-based chemicals, such as wax esters for use as high-grade lubricants. The challenge of the business concepts for these crops is the development of cultivars with a high production and quality.

- Breeding challenges for *Calendula* are increasing seed production per hectare from 1500 to 3000 kg/ha (this would then be similar to the yield of oil seed rape) and increasing seed oil content from 15 to 25%.
- Breeding challenges for *Crambe* are the production of wax esters by introducing fatty alcohol and wax ester genes and a further increase in erucic acid production per hectare through higher seed production, higher oil content, and higher erucic acid content in the oil.

*Source: Wageningen University*

***Starch potato as production platform for special starches & protein. EU potential acreage: 500 000 ha.***

The starch potato has a well-developed production chain, mainly based on starch. There are more than three hundred starch-based products with markets in food, animal feed, and industrial applications. The use of degradable plastics and biomaterials of modified starch is one of the success examples. The business concept for potato aims at the creation of added value by utilising all constituents and by increasing the recoverability of those constituents. Breeding and green biotechnology are offering tools for making novel starches with improved properties; this can considerably increase the range of applications, and thus market volume.

The main breeding targets are:

- Optimisation of starch properties and production of new high-grade starches for existing and new applications;
- Improvement of the cell wall structure to increase the extractability of starch and protein;
- Increasing the protein content without lowering the starch content;
- Improvement of the properties of pectin to enable applications in medical and industrial products;
- Increasing the content of high-grade components for pharmaceutical applications and nutraceuticals, and improvement of their accumulation by cellular compartmentalisation.

*Source: Wageningen University*

In the case of **Plant-Made Pharmaceuticals (PMPs**), also referred to as bio pharming, the viability of the business model has not yet been fully proven. Plants species are improved via genetic engineering so that they can produce certain types of therapeutically important proteins and associate molecules such as peptides and secondary metabolites. The proteins and molecules can then be harvested and used to produce pharmaceuticals.

Compared to conventional production methods, plant-made pharmaceuticals could save substantial time, money, and provide a system for producing proteins that could solve current production challenges.

*Arabidopsis* is often used as a model organism to study gene expression in plants, while actual production may be carried out in maize**,** rice**,** potatoes**,** tobacco**,** flax or safflower. There is much debate over the practicality of using plants to produce proteins. Some groups fear that contamination of conventional crops might occur. Conventional production methods for pharmaceutical proteins involve substantial investments of both time and funds. For pharmaceutical companies, PMP production is like any other pharmaceutical production system and it is not a commodity agricultural production system (Monsanto Protein technologies, 2004[19]).

Although no drugs from pharm crops are currently on the market, open field growing trials of these crops began in the United States in 1992 and have taken place every year since.

**Other examples of biochemical production are specialty chemicals and enzymes (multiple opportunities ranging from surfactants and waxes for pigments to flavours and fragrances) , plant-derived oils as industrial feedstocks (lubricants, polymers, paints and solvents to inks, dyes, cosmetic products and surfactant), polymers (starch and rubber), and fibres (improvement of plant fibres via maize and poplar)** (Koops, 2010). None of these specific goals have led to significant achievements to date.

### 3.1.4 Cross-cutting issue: Impact of climate change on plant breeding

Climate change will lead to higher temperatures and changed precipitation patterns. As a consequence, plants need to be adapted to new agro-climatic conditions (Ceccarelli, 2010; Chakraborty, 2011; Heller, 2009; Lobell, 2008; Luck, 2011; Reynolds, 2010; Schutter, 2011; Shyam-Singh, 2011). Climate change will require different production systems, certain crops will expand to new regions and completely new crops will be introduced, from all perspectives implying the need for new varieties if agriculture is to remain competitive and sustainable.

Additional adverse effects are the likely increased frequency of abiotic stresses such as heat and drought, and the increased frequency of biotic stresses (pests and diseases). Eventually, climate change might cause losses of biodiversity, mainly in marginal environments (Heller, 2009).

[19] http://www.pugwash.org/reports/ees/cuba2004/01%20Pugwash/04_Cama.pdf

Plant breeding has already addressed both abiotic and biotic stresses. Commercial breeding programs already work with these objectives and, as changes occur gradually, it is not anticipated that adaptation to climate change will significantly alter present plant breeding targets. However strategies of adaptation to climate change may include increased access to a suite of diverse varieties with different life-cycle durations to escape occurrences of stress at critical periods during the crop life and improved water use efficiency. These measures will go hand in hand with breeding for resistance to biotic stresses using all available breeding techniques (from conventional to modern biotechnologies) (Aberton, 2010).

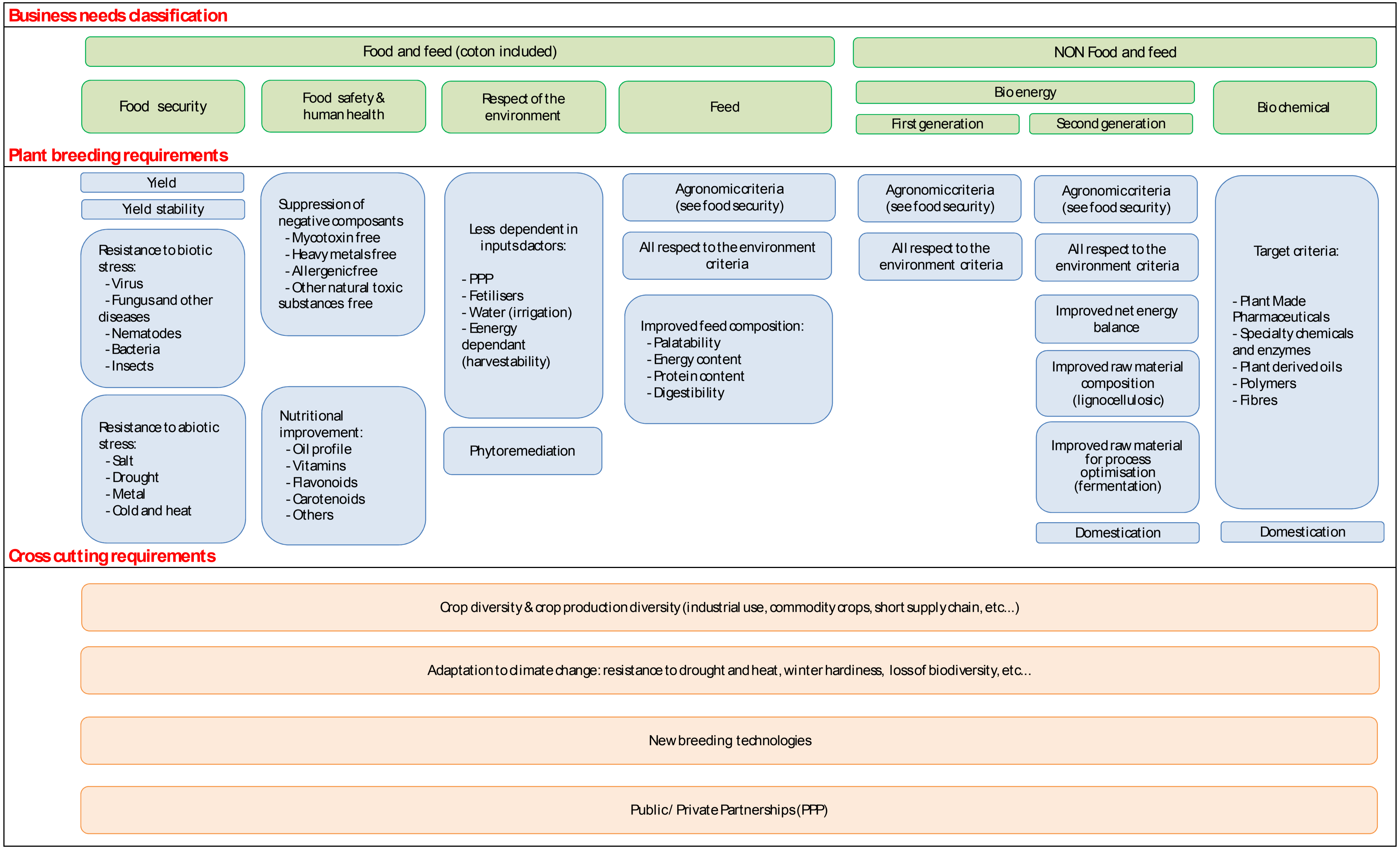
### 3.1.5 Summary: Typology of the plant breeding needs

On the basis of that analysis, a general classification of plant breeding needs is drafted in relation to the different business sectors grouped in three themes:

- Food and feed;
- Non-food - bio energy;
- Non-food - bio chemicals.

Several additional and cross cutting requirements have also been identified for all sectors.

**Figure 4 – Breeding needs per agro-food supply chain business sector**




*Source: compiled by Arcadia International*

This typology of breeding needs presents in depth the major breeding objectives without considering neither prioritisation nor market opportunities; therefore it does not capture the importance of the breeding efforts for each sector. This aspect is further analysed in Chapter 4. Additionally, it should be highlighted that breeding schemes are optimised to address several breeding objectives whenever possible. This is shown by the following examples that have additional complexity and help understand the global breeding efforts per trait.

***Grass as source of protein, fibres, and fermentable sugars.***

Sown pasture covers 8% of the EU agricultural land. Grassland is for a large part grazed by cattle; annual average grass production is at maximum 8 t dry matter per hectare. With different grass management systems, mowing instead of grazing, yield can be doubled if cut grass would be refined into protein, fibre, and fermentable sugars. This would not only make it possible to produce sufficient feed for the existing livestock but would also allow production of better formulated feed for cattle, pigs and poultry. This would mean a step in further improving sustainability of animal husbandry. The extra grass biomass (8 ton/ha) harvested in the new system can be used as source of valuable industrial raw materials. The challenge is to develop the most suitable grass cultivars for this system and at the same time initiating the development of post-harvest biorefinery techniques. Breeding challenges are:

- Maximum productivity per hectare under the mowing regime;
- Increasing protein content;
- Improvement of the dissolution of cell walls in older and more fibrous grass material by developing genotypes with easier degradable cell walls.

***Biorefinery of maize straw for feed, biofuels and biochemicals***

Maize is one of the world's largest agricultural crops and is an important source of food, animal feed and of raw materials for a large number of industrial applications. The possibilities of the crop as supplier of raw materials for a biobased economy are hardly utilised in Europe. Room for a large expansion of the cultivation of Corncob maize and/or wet grain maize for pig husbandry is expected in Europe. This has the direct environmental advantage that less concentrated feed needs to be imported. Setting up of a biorefinery chain for the remaining maize straw is proposed to enable this development. This development will make a positive contribution to the environment ($CO_2$ mitigation, more bioenergy) and thus to the sustainability of pig husbandry in Europe.

The main breeding challenges for maize straw are:

- Improvement cell wall composition to improve the digestibility of lignocellulosic biomass for the production of 2nd generation ethanol and other white biotech products;
- Improvement of amount, quality and extractability of proteins;
- Optimisation of starch amount and properties.

*Source: Wageningen University*

## 3.2 What are the likely breeding approaches that are considered to address these needs?

Since the mid-1980s onwards, major changes have taken place in plant breeding as the result of the introduction and routine use of new techniques and modern biotechnologies. Until then commercial breeding was based on traditional/conventional methods most of them applied in the field and on a limited number of laboratory technologies such as *in vitro* multiplication of plant propagating material and the production of haploid plants (mainly double haploids) for the rapid development of homozygous lines.

In the 1970s there were several relevant scientific advances in fundamental biology, such as the discovery of restriction enzymes for the fragmentation of DNA, the development of technologies for determining the base sequence of the DNA, and later on for the development of high-throughput sequencing and screening.

These breeding molecular techniques continue to improve at high speed and they are part of the actual plant breeders' tool box for a large majority of crops. These techniques are rather expensive and therefore not all SME's breeders have access to these techniques. This element has led to the appearance of service providers in the area of molecular breeding (e.g. Keygene). Instead of developing an internal capacity in this field, a significant proportion of breeders prefer to outsource that activity to these service providers.

Most of these techniques are grouped under the generic term of molecular breeding. The main technologies in used today by breeders can be summarised as follows:

- Molecular marker technology: Marker technologies are like signposts that identify characteristics of the phenotype or the genotype along the DNA of an organism (then, of a plant) and so their inheritance can be followed through generations.. The technologies that have been most useful for breeding applications are named *restriction fragment length polymorphisms* (RFLP), *microsatellites* (SSR) and *single nucleotide polymorphisms* (SNP). Those breeding applications include characterising germplasm, assessing genetic diversity in the given crop genepool, and very importantly monitoring of the presence of target traits in different generations through the so-called "marker-assisted selection". .The use of marker technologies represents higher accuracy and speed in the analysis of germplams and the selection of plants for the presence of relevant traits. Altogether these technologies reduce the time to deliver new varieties, which means better cost-efficiency of the breeding scheme. In the last 10-15 years, the advantages of using markers have been amplified; this is so because of 1) the automatization of many of the technologies that allows collecting more data, 2) the use of bioinformatics that helps to understand data, 3) the emergence of a new mode of operation via outsourding of marker services, and 4) the decrease of costs per unit of data.
- Genetic modification. Genetic modification implies the introduction of specific genetic components in a cell so that the plant can express a given phenotype that originally lacks. This transfer of DNA may be done via several techniques such as the use of the bacterium *Agrobacterium tumefaciens* and particle bombardment. Genetic modification has been mostly used in maize, soybean, cotton and rapeseed. Research is on-going in several other crops such as eggplant, wheat, rice, potatoes, etc... Most GM varieties that have been commercially released to date have originated in the private sector. One of a few exceptions is the GM papaya that was developed by the public sector. Development of GM varieties has targeted mainly insect resistance and herbicide resistance. Most of the research focuses on other traits such as stress tolerances but also on traits such as product quality (e.g. vitamins). It is expected that this technology will continue to be used for such traits as well as novel traits related to development of varieties for the non-food market segments (second generation of biofuel crops and for other industrial uses of plants). The main limitations of using these technologies are research-based (including intellectual property issues), which result in significant time for development, and very importantly testing prior to release to comply with country or EU regulations.
- Mutagenesis is a process by which the genetic makeup of an organism changes in a stable manner, as a result of a mutation. It may occur spontaneously in nature or as a result of experimental exposure to mutagens (physical, chemical and biological agents) in the laboratory.. Several examples of commercial varieties obtained via mutation exist in ornamentals, vegetable crops and in agricultural crops (herbicide tolerance).
- Next to the molecular marker technologies and genetic modification methods described above, a number of new plant breeding techniques have been developed and are currently used or under test by a number of breeding companies. Some of these new technologies are subject to a possible EU regulation[20] when others are not (e.g. apomixis).

This brief introduction highlights the fact that most of plant breeders have, today, different techniques available to develop new cultivars. Seed companies have to decide which route(s) to take and which technology(ies) to use to release a specific trait. Business decisions are based on several key factors (mainly time/speed to market, cost to deliver, availability of modern techniques, complexity of the trait, protection issues, and intellectual property issues).

Therefore, for any of the traits listed in Figure 4, several different breeding approaches may be applied. To the conventional plant breeding methods, additional methods mainly based on molecular technologies may apply.

For the purpose of this analysis the following classification based on the approach taken by Van de Wiel et *al.* [21] has been considered:

- Conventional breeding: all breeding techniques that have been used by breeders before introduction of biotechnologies. These techniques are mainly applied in field nurseries;
- Non-regulated biotech: Molecular techniques are novel techniques used by breeders to develop plants/varieties not covered by the EU Directive 2001/18/EC;
- Regulated biotech: Any molecular technique applied by breeders to develop plants/varieties covered by the EU Directive 2001/18/EC and under consideration by the EC[22].

The following assessment summarised the perception and understanding of the experts that were contacted during the first part of the study regarding the most likely approach.

[21] C. Van de wiel, J. Schaart, R. Niks, and R. Visser. 2010. Traditional plant breeding methods. Wageningen UR Plant Breeding, Report 338. 66p.

[13,22] See JRC Report on new plant breeding techniques. State-of-the-art and prospects for commercial development. M. Lusser and *al*. 2011

**Table 2 – Likely preferred plant breeding approach(s) to breeding needs**

| Business objective | | Breeding needs | | Likely breeding approach to deliver the trait of interest | | |
|---|---|---|---|---|---|---|
| | | | | Conventional | Non regulated biotech | EU regulated biotech |
| Food and feed (coton included) | Food security (agronomic criteria) | Crop productivity | Yield | +++ | + | + |
| | | | Yield stability | + | + | + |
| | | Resistance to biotic stress | Virus | + | +++ | ++ |
| | | | Fungus and other diseases | + | +++ | ++ |
| | | | Nematodes | + | ++ | + |
| | | | Insects | + | +++ | ++ |
| | | | Bacteria | + | + | + |
| | | Resistance to abiotic stress | Salt | + | ++ | + |
| | | | Drought | ++ | +++ | ++ |
| | | | Metal | + | + | + |
| | | | Cold & heat | +++ | ++ | + |
| | Food safety & plant health | Suppression of negative composants | Mycotoxin free | n.a. | ++ | + |
| | | | Heavy metals free | + | + | + |
| | | | Allergenic free | + | ++ | + |
| | | | Other natural toxic substances free | + | ++ | + |
| | | Nutritional improvement | Oil profile | ++ | +++ | ++ |
| | | | Vitamins | + | +++ | ++ |
| | | | Flavonoids | + | +++ | ++ |
| | | | Carotenoids | + | +++ | ++ |
| | | | Others | + | +++ | ++ |
| | Respect of the environment | Less dependent in input factors | PPP | ++ | +++ | ++ |
| | | | Fertilisers | + | + | + |
| | | | Water | ++ | +++ | ++ |
| | | | Energy | +++ | +++ | ++ |
| | | Phytoremediation | | + | ++ | + |
| | Feed | Agronomic criteria | See food security and environmental criteria | See above | | |
| | | Environmental criteria | | | | |
| | | Improved feed composition | Palatability | + | +++ | ++ |
| | | | Energy content | ++ | +++ | ++ |
| | | | Protein content | ++ | +++ | ++ |
| | | | Digestibility | ++ | +++ | ++ |
| Non food and feed | Bio energy (First generation) | Agronomic criteria | See food security and environmental criteria | See above | | |
| | | Environmental criteria | | | | |
| | Bio energy (second gneration) | Agronomic criteria | See food security and environmental criteria | See above | | |
| | | Environmental criteria | | | | |
| | | Specific criteria (improved characteristics | Improved net energy balance | + | +++ | ++ |
| | | | Improved raw material composition | + | +++ | ++ |
| | | | Improved raw material for process optimisation | + | +++ | ++ |
| | | Domestication | | ++ | +++ | ++ |
| | Bio chemical | Target products | PMP | n.a. | +++ | ++ |
| | | | Specialty chemicals & enzymes | n.a. | +++ | ++ |
| | | | Plant derived oils | + | +++ | ++ |
| | | | Polymers | + | +++ | ++ |
| | | | Fibres | + | +++ | ++ |
| | | Domestication | | + | +++ | ++ |

*Source: Compiled by Arcadia International*
*Note: +: unlikely; ++: likely; +++: highly likely*

Plant breeding processes are crop specific to the point that until recently it was considered that a maize breeder could not breed sugar beet and vice and versa as breeding approaches are largely different and highly specific to the crop species.

During the last 30 years, new techniques appeared in the breeder tool box providing several solutions on how to set-up individual breeding programmes.

Conventional breeding remains the main approach as all new cultivars will have to be tested in field trials and therefore conventional breeding cannot be avoided within the commodity supply chain.

Plant breeders constantly strive to breed new varieties that yield more, resist emerging pests and pathogens, tolerate heat and drought, and grow in marginal soils and environments. Increasingly, molecular tools are used to speed those efforts. By identifying genes associated with desirable traits, scientists don't have to wait for time-consuming field observations. To grow wheat and evaluate it for traits in the field it takes 5 to 9 years. Using genomic data, it can be done in about 6 months.

Though molecular tools speed up the process, they also require analysing massive amounts of data and are much more expensive than conventional breeding. Therefore the selection of the breeding tool also depends of the added value it brings. Modern techniques are less developed in cereal crops than in hybrid crops as added value of cereal seed is low compared hybrid seed.

Even with modern molecular tools, breeders face challenging traits like drought tolerance and high yield, which result from the combined action of multiple genes, each having a small effect. These genes, called "quantitative trait loci" (QTLs), are stretches of DNA that affect an observable trait. The conventional marker-assisted selection (MAS) approach has limited power when a trait is affected by small-effect genes. The sheer volume of data involved forces MAS to exclude some small-effect QTLs when individual plants are selected for further breeding. In such cases more robust genomic and biotechnologies methods are required.

When breeders are integrating new breeding tools, it concerns the germplasm evaluation and variety development phases. Molecular breeding is today widely used for germplasm characterisation and e.g. for speeding-up back-crossing a trait of interest.

These new tools are integrated in breeding programmes when new technologies can be used in a routine mode at an affordable cost (cost-effectiveness). For certain crop species, technologies are not yet available and/or too expensive. In these cases, only conventional breeding applies.

Additionally new breeding tools may not be adapted to new tools actually developed. It is more difficult to use molecular tools for market assisted selection for complex traits involving multiple genes. In these cases, back-crossing cannot be used or is too expensive to be used in routine.

Finally, new breeding methods are preferred when assessment of a given trait can be done in laboratory and doesn't require a field activity.

These different elements lead to the classification presented in the table above.

Yield stability is rated as "unlikey" for the three approaches as breeding can hardly assess yield stability. Instead, the stability of a given variety is assessed during the post-registration trials in large national and regional field testing networks in which management practices are introduced. Breeding can only start identifying stability properties of new cultivars.

New breeding techniques that are falling under the scope of the EU GMO Directive 2001/18/EC on the environmental release of GMO that provides for the pre-market authorisation of GMOs are considered to be unlikely used by the EU plant breeders as the future acceptance of cultivation of GM crops in the EU remains uncertain. As an illustration of this situation, it can be noticed the rapid reduction of number of GM field trials in the EU over the last 10 years. Biotechnology tools are being used when no regulatory barriers are present based on a cost/benefit analysis. Breeders prefer to avoid using these approaches in order to secure access to the market. However, these technologies may be used in the trait development phase (pre-breeding) for proof of concept before using conventional breeding and novel non-regulated techniques for delivering the trait to the market.

Objectives not related to food and feed production mainly take place in the context of an integrated supply chain meaning that an identity preservation scheme is established. For example, production of PMP will be done on a rather limited acreage based on contractual agreements between farmers and the pharmaceutical industry. The economic value of this supply chain is largely higher than for commodity crops and therefore modern techniques can be introduced for the breeding of varieties containing pharmaceutical compounds. Additionally, only modern techniques can help maintaining quality, purity and traceability of the given compounds. This logic applies to all needs of the non-food and feed category to the exception of biofuels of first generation as these biofuels are using raw material from the commodity supply chain.

**Table 3 - Estimated cost to deliver breeding needs**

| Business objective | | Breeding needs | Low | Medium | High |
|---|---|---|---|---|---|
| Food and feed (coton included) | Food security | Crop productivity | *Yield* | | *Yield stability* |
| | | Resistance to biotic stress | *Fungus and other diseases*<br>*Insects* | *Virus*<br>*Nematodes*<br>*Bacteria* | |
| | | Resistance to abiotic stress | *Drought* | *Salt*<br>*Metal*<br>*Cold & heat* | |
| | Food safety & plant health | Suppression of negative composants | | *Mycotoxin free*<br>*Heavy metals free*<br>*Allergenic free*<br>*Other natural toxic substances free* | |
| | | Nutritional improvement | *Oil profile* | *Vitamins*<br>*Flavonoids*<br>*Carotenoids*<br>*Others* | |
| | Respect to the environment | Environmental criteria | *Less dependant to PPP*<br>*Less dependant to water* | *Less dependant to fertilisers*<br>*Less dependant to energy* | *Phytoremediation* |
| | Feed | Improved feed composition | *Energy content*<br>*Protein content*<br>*Digestibility* | *Palatability* | |
| Non food and feed | Bio energy | Second generation & domestication | | *Improved net energy balance*<br>*Improved raw material composition*<br>*Improved raw material for process optimisation* | *Domestication* |
| | Bio chemical | Target products & domestication | | *Plant derived oils*<br>*Fibres*<br>*Domestication* | *PMP*<br>*Speciality chemicals & enzymes*<br>*Polymers* |

*Source: Compiled by Arcadia International*
*Low, medium and high costs refer to resources, time and total cost to deliver a given trait. Differences in costs to deliver a given trait are based on the difficulties to breed that trait (complex involving a large number of genes vs simple traits involving a single trait)*

Breeding costs are trait by crop specific and largely depend of the length of the breeding cycle and the breeding tools used. Literature doesn't present any robust data regarding the cost of delivering of a new cultivar to the market place.

Table 3 presents an estimation of the costs performed by the study team based on inputs collected during the interviews with experts.

Yield is considered as low as it is already in place for years. Therefore breeding schemes and breeding methodologies to assess yield potential of a variety are already integrated in the breeding programmes and no additional costs are required.

Yield stability of a given variety is approached by measuring the G x E interaction. Additionally crop management has to be included leading to a field testing approach that has to consider the genotype, the environment and the crop management (G x E x M). This approach requires a large multi-locations' testing over years in agronomy research trials in which specific crop management approaches (e.g. high vs. low inputs) can be tested. Most of this work is performed after registration is large networks called post-registration or recommendation trials mainly managed by national agronomy research organisations (e.g. NIAB in the UK; Arvalis and CETIOM in France, etc…) and in advisory services networks (e.g. cooperatives) as well as in seed companies field testing networks.

Costs to deliver cultivars for biochemical production seem to be very high as modern tools are required to ensure product quality.

**Table 4 – Timelines for first commercialisation**

| Business objective | | Breeding needs | Timelines for 1st commercialisation | | | |
|---|---|---|---|---|---|---|
| | | | Already marketed | Short term | Mid term | Long term |
| Food and feed (coton included) | Food security | Crop productivity | *Yield*<br>*Yield stability* | | | |
| | | Resistance to biotic stress | *Virus*<br>*Fungus and other diseases*<br>*Nematodes*<br>*Insects*<br>*Bacteria* | | | |
| | | Resistance to abiotic stress | | *Drought* | *Salt*<br>*Cold & heat* | *Metal* |
| | Food safety & plant health | Suppression of negative composants | | | *Mycotoxin free* | *Heavy metals free*<br>*Allergenic free*<br>*Other natural toxic substances free* |
| | | Nutritional improvement | *Oil profile* | *Vitamins* | *Flavonoids*<br>*Carotenoids*<br>*Others* | |
| | Respect to the environment | Environment aspects | *Less dependant to PPP*<br>*Less dependant to water*<br>*Phytoremediation* | | *Less dependant to fertilisers*<br>*Less dependant to energy* | |
| | Feed | Improved feed composition | *Palatability*<br>*Energy content*<br>*Protein content*<br>*Digestibility* | | | |
| Non food and feed | Bio energy | Second generation & domestication | | | *Improved net energy balance*<br>*Improved raw material composition*<br>*Improved raw material for process optimisation* | *Domestication* |
| | Bio chemical | Target products & domestication | | *PMP*<br>*Fibres*<br>*Domestication* | *Plant derived oils* | *Specialty chemicals & enzymes*<br>*Polymers* |

*Source: Compiled by Arcadia International*

This table present the current situation related to the delivery of traits to the market. It highlights which traits are already marketed and for other traits the estimated time to placing to the market the first variety containing the given trait. These estimations are based on experts' opinions rather than on hard data. As an hypothesis, one may consider that these types of traits will be accepted by the EU consumers and that varieties containing such type of GM traits will be cultivated in the EU only a couple of years after market introduction in other parts of the world.

We have classified each trait in three classes (short, medium and long term). Short term means a 5 to 8 years period, medium term means in between 8 to 15 years and long term means a period longer than 15 years.

Literature shows that new cultivars tolerant to drought enriched in vitamins (e.g. golden rice) and in fibres should be marketed in the coming 3 to 5 years but mainly outside the EU as they have been developed by using genetic engineering.

**Table 5 - Actual breeding priorities**

| Business objective | | Breeding needs | Actual breeding priority | | |
|---|---|---|---|---|---|
| | | | Low | Medium | High |
| | | Crop productivity | | *Yield stability* | *Yield* |
| | | Resistance to biotic stress | *Virus*<br>*Nematodes*<br>*Bacteria* | *Fungus and other diseases*<br>*Insects* | |
| | | Resistance to abiotic stress | *Salt*<br>*Cold & heat*<br>*Metal* | | *Drought* |
| | Food safety & plant health | Suppression of negative composants | *Mycotoxin free*<br>*Heavy metals free*<br>*Allergenic free*<br>*Other natural toxic substances free* | | |
| | Food safety & plant health | Nutritional improvement | *Flavonoids*<br>*Carotenoids*<br>*Vitamins*<br>*Others* | | *Oil profile* |
| | Respect of the environment | Environment aspects | *Less dependant to fertilisers*<br>*Phytoremediation*<br>*Less dependant to energy* | *Less dependant to PPP* | *Less dependant to water* |
| | Feed | Improved feed composition | | *Palatability* | *Energy content*<br>*Protein content*<br>*Digestibility* |
| Non-food and feed | Bio energy | 2nd generation & domestication | *Improved net energy balance*<br>*Improved raw material composition*<br>*Improved raw material for process optimisation*<br>*Domestication* | | |
| Non-food and feed | Bio chemical | domestication | *PMP*<br>*Specialty chemicals & enzymes*<br>*Plant derived oils*<br>*Polymers*<br>*Fibres*<br>*Domestication* | | |

*Source: Compiled by Arcadia International*

Breeding objectives are defined based on the business opportunities but also on the cost-effectiveness of the breeding scheme.

Table 5 shows; that based on the study team expertise and on inputs from interviewees, that quite a lot of quality criteria are considered as low priority by breeders. This can be explained by the main fact that no premium is given to the farmer for e.g. cereal grain containing more vitamins. Therefore as business opportunities are not present, breeding efforts are limited. Past experiences in some oil crops such as oil seed rape show that when premium are granted to farmers for an improved oil profile, breeders integrate these research priorities in their breeding programmes.

The current EU policy on the sustainable use of pesticides (Framework Directive 2009/128/EC) has as major objective to reduce the impact of use of pesticides on human health and on the environment. The reduction of impacts is often associated to the reduction of PPP treatment frequency. Reducing the number of PPP treatments on a given crop can be achieved by improving spraying's equipment but also by growing cultivars more resistant/tolerant to plant pests and diseases. Plant breeding has already integrated these needs for several decades and are more oriented towards the development of resistant cultivars as less pesticides are available.

Breeding priorities for non-food and feed objectives are considered as low as these business opportunities are rather new. These businesses will certainly expand in the future and breeding efforts for these traits will then expand in parallel.

**Participative plant breeding (PPB): a new approach?**

Alongside the dominant conventional agricultural practices, an agriculture strongly connected to its environment has been preserved and is now re-emerging in Europe. This alternative agriculture is based on different varieties than conventional agriculture, ones with strong local adaptation and cultural values (Osman and Chable 2009). The development of low-input or non-conventional agricultural practices is also related to the diversification of public demands, in particular for organic farming and local products (Desclaux et al 2009). These agricultural systems are based on varieties covering a wide range of genetic states and categories, for which the criteria of stability and homogeneity are not intrinsic qualities and are not necessarily required (Chable *et al*, in press).

Vernooy (2003) broadly defined Participatory Plant Breeding (PPB) by approaches that involve close collaboration between researchers and farmers, and potentially other stakeholders, to bring about genetic improvements within crops. In the conditions where it is mostly applied, participatory plant breeding (PPB) is an organization of the plant breeding process which aims to answer several questions at the same time: (1) at the production level, the needs of specific varieties associated to the absence of adapted varieties on the market and no interest for seed companies, (2) at the ecological level, the means to develop cultivated biodiversity for more sustainable agroecosystems, (3) at socio-economical level, the wish of some groups of farmers to get more empowerment and to become self-sufficient for their seed input. Participatory approaches emerged in the 1990s in the south countries to better fit the needs of the marginal areas where the varieties bred for the Green Revolution couldn't be cultivated and has since been described by several authors (Almekinders and Elings, 2001; Ceccarelli et al, 2000, 2003; Machado and Fernandes, 2001; Sperling et al. 2001; Vernooy, 2003; Weltzien et al, 2008; Witcombe et al, 2001).

In Europe, PPB has recently been adopted as a useful set of breeding methods for organic plant breeding, as the latter was stimulated by the European Organic Agriculture Regulation (834/2007) in 2004 (Chable, et al. 2008). Apart from representing a useful tool for appropriate breeding, the implementation of PPB has the potential to increase the genetic diversity of crops at a regional level and be a dynamic form of *in situ* genetic conservation (Ceccarelli 1996, Patto et al, 2008). A recent review stresses the necessity that new tools in genetics and social sciences be co-developed to improve methods of addressing the complexity of agro-ecological systems (Thomas et al, 2011).

PPB is expected to produce more benefits than the traditional global breeding model in situations where a highly centralised approach is inappropriate[23]. Situations in which PPB is expected to be particularly advantageous include the following:

- Improvement of crops that are mainly of local interest and hence do not attract the attention of commercial breeding programs;
- Improvement of crops grown in marginal environments characterised by subsistence-oriented agriculture;
- Improvement of crops grown in highly variable environments which preclude widespread use of individual varieties;
- Situations in which end users require uncommon traits;
- Situations in which end users require unusual combinations of common traits.

At the European level, it has to be noticed the creation in 2012 of the European Coordination for farmers' seed, which constitutes a network of the different national networks. The current members are: Réseau Semences

[23] Weltzien et al, 2000

Paysannes (France), Rete Semi Rurali (Italy), Red de Semillas (Spain), Pro Species Rara (Switzerland), Arche Noah (Austria), Scottish Crofting Federation (UK).

The creation of the European coordination was helped by a European project: Farmer's Seeds Project - Best Practices in Sustainable Agriculture and Food Sovereignty[24] (funded by the UE commission for 36 months, 1,300 K Euros with Italy, France, Scotland, Romania, Hungary, Senegal and Tunisia, 2009-2011).

Literature review shows that there is a large consensus on the future role of public plant breeding activities. Participatory plant breeding (PPB) is not an exception as researchers involved in PBB belongs to public institutions (national or international). Nevertheless, the next chapters of this report do not consider PPB as no data related to the actual efforts have been compiled to date. Instead, we present an introduction of PPB objectives and list the main current initiatives in Annex 2.

## 3.3 Prioritisation and breeding (business) opportunities (which traits for which crops?)

Not all of the traits listed in Figure 4 and Table 5 are breeding objectives in all crops covered by the study. The following table presents the traits that are (likely) breeding objectives for commercial plant breeders.

While the private breeders' objectives to cover food and feed needs are rather well known, the situation is much more unclear for the non-feed and feed needs. Therefore the analysis that is presented in the following table is more based on experts' impressions than on concrete evidences.

**For agricultural crops, plant breeders are traditionally releasing varieties to crop production systems for commodity market.** Therefore it is important that new cultivars bring to farmers with characteristics that would allow the best economic return as possible. For this reason, plant breeders are used to breed varieties with a high yield potential and possibly an optimal yield stability (in time and in space and tested on the basis of the G x E interaction). Therefore the main traits considered by plant breeders is yield potential completed by selected resistance biotic and abiotic traits that have been selected to prevent for any yield potential loss in farmers' fields.

**For vegetable crops, yield (quantity) is associated to other qualitative criteria.**

**While criteria related to food safety and respect to the environment start to be considered by commercial plant breeder; most of non-food & feed breeding needs seem to be considered by a limited number of actors.** For example, the plant made pharmaceuticals (PMP) seem to be developed by a small number of pharmaceutical companies under an identity preserved production scheme. Acreage potential will remain marginal for biochemical production.

[24] (http://www.farmerseeds.org/ ) 'Farmer's Seeds - Best Practices in sustainable Agriculture and Food Sovereignty: development of an inclusive approach in the Fight against Poverty' - DCI NSA ED/2009/201-955; NSA: Non-state actors and local authorities in development.

## Table 6 - Likely crop/trait combinations considered as breeding objectives by plant breeders

| Business objective | | Breeding needs | | Cereals | | | Oilseeds | | | Fodder plants | | | Fruits | | Vegetables | | | Industrial crops | | | Others | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Winter wheat | Maize | Triticale | Sunflower | Winter OSR | Soybean | All gramineae | All legumes | Wine | Apple | Potatoes | All Brassiceae | All tomatoes | All lettuces | Sugar beet | Hop | Cotton | Miscanthus | Jatropha | Poplar | Others |
| Food and feed (coton included) | Food security (agronomic criteria) | Crop productivity | Yield | √√√ | √√√ | √√√ | √√√ | √√√ | √√√ | √√√ | √√√ | √ | √√√ | √√√ | √√ | √√√ | √ | √√√ | √√√ | √√√ | | | | |
| | | | Yield stability | √√√ | √√√ | √√√ | √√√ | √√√ | √√√ | √√√ | √√√ | √ | √√√ | √√√ | √√ | √√√ | √ | √√√ | √√√ | √√√ | | | | |
| | | Resistance to biotic stress | Virus | √ | √ | √ | √ | √ | √ | √ | √ | √√ | √√√ | √√√ | √√ | √√√ | √√√ | √√√ | √√ | √ | | | | |
| | | | Fungus and other diseases | √√√ | √ | √√√ | √√ | √√ | √ | √√ | √ | √√√ | √√√ | √√√ | √√√ | √√√ | √√√ | √√ | √ | √ | | | | |
| | | | Nematodes | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √√√ | √ | √ | √ | √√√ | √ | √ | | | | |
| | | | Insects | √ | √√√ | √ | √ | √√ | √√ | √ | √ | √√√ | √√ | √ | √ | √ | √ | √ | √ | √√√ | | | | |
| | | | Bacteria | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √√√ | √ | √ | √ | √√√ | √ | √ | | | | |
| | | Resistance to abiotic stress | Salt | √ | √ | √ | √ | √ | √ | √ | √ | √ | √√ | √ | √ | √ | √ | √ | √ | | | | | |
| | | | Drought | √√ | √√√ | √√ | √√√ | √√ | √√√ | √√ | √√ | √√ | √√ | √√ | √ | √ | √ | √ | √ | √ | | | | |
| | | | Metal | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | | | |
| | | | Cold & heat | √ | √ | √ | √ | √√ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | | |
| | Food safety & plant health | Suppression of negative composants | Mycotoxin free | √ | | √ | | | | | | | | | | | | | | | | | | |
| | | | Heavy metals free | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | | |
| | | | Allergenic free | √√√ | √√ | √√ | √√ | √√√ | √√√ | √ | √ | √√√ | √√√ | √√√ | √√√ | √√√ | √√√ | √√√ | √√√ | √√√ | | | | |
| | | | Other natural toxic substances free | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | | |
| | | Nutritional improvement | Oil profile | | √√ | | √√√ | √√√ | √√√ | | | | | | | | | | | | | √√√ | | √ |
| | | | Vitamins | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | | | |
| | | | Flavonoids | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | | | |
| | | | Carotenoids | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | | | |
| | | | Others | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | | | |
| | Respect of the environment | Less dependent in input factors | PPP | √√ | √√ | √√ | √√ | √√ | √√ | √√ | √√ | √√ | √√ | √√ | √√ | √√ | √√ | √√ | √√ | √√ | | | | |
| | | | Fertilisers | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | | |
| | | | Water | √ | √√√ | √ | √√√ | √ | √√√ | √ | √ | √√ | √√ | √√ | √ | √√ | √√ | √ | √ | √√ | | | | |
| | | | Energy | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | | |
| | | Phytoremediation | | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| | Feed | Agronomic criteria | See food security and environmental criteria | See above | | | | | | | | | | | | | | | | | | | | |
| | | Environmental criteria | | | | | | | | | | | | | | | | | | | √√ | √√ | √√ | √√ |
| | | Improved feed composition | Palatability | √ | √√√ | √ | √ | √ | √√√ | √√√ | √√√ | | | | | | | | | | | | | |
| | | | Energy content | √ | √√√ | √ | √ | √ | √√√ | √√√ | √√√ | | | | | | | | | | | | | |
| | | | Protein content | √√ | √√ | √√ | √√ | √√ | √ | √√√ | √√√ | | | | | | | | | | | | | |
| | | | Digestibility | √ | √√ | √ | √ | √ | √√ | √√√ | √√√ | | | | | | | | | | | | | |
| Non food and feed | Bio energy (First generation) | Agronomic criteria | See food security and environmental criteria | See above | | | | | | | | | | | | | | | | | | | | |
| | | Environmental criteria | | | | | | | | | | | | | | | | | | | √√ | √√ | √√ | √√ |
| | Bio energy (second gneration) | Agronomic criteria | See food security and environmental criteria | See above | | | | | | | | | | | | | | | | | | | | |
| | | Environmental criteria | | | | | | | | | | | | | | | | | | | √√ | √√ | √√ | √√ |
| | | Specific criteria (improved characteristics | Improved net energy balance | √ | √ | | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | √ | √ | √ | √ | √ | √ |
| | | | Improved raw material composition | √ | √ | | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | √ | √ | √ | √ | √ | √ |
| | | | Improved raw material for process optimisation | √ | √ | | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | √ | √ | √ | √ | √ | √ |
| | | Domestication | | | | | | | | | | | | | | | | | | | √√√ | √√√ | √√√ | √√ |
| | Bio chemical | Target products | PMP | √ | √ | | √ | √ | √ | √ | √ | | | √ | √ | √ | √ | √ | √ | √ | | | | √√√ |
| | | | Specialty chemicals & enzymes | √ | √ | | √ | √ | √ | √ | √ | | | √ | √ | √ | √ | √ | √ | √ | | | | √√√ |
| | | | Plant derived oils | √ | √√ | | √ | √ | √ | √ | √ | | | √ | √ | √ | √ | √ | √ | √ | | | | √√√ |
| | | | Polymers | √ | √ | | √ | √ | √ | √ | √ | | | √ | √ | √ | √ | √ | √ | √ | | | | √√√ |
| | | | Fibres | √ | √ | | √ | √ | √ | √ | √ | | | √ | √ | √ | √ | √ | √ | √√√ | | | | √√√ |
| | | Domestication | | | | | | | | | | | | | | | | | | | | | | √√√ |

*Source: Compiled by Arcadia International*

*Note: √: low consideration by breeders; √√: Medium consideration by breeders; √√√: high consideration by breeders. In black: Not Applicable*

## 3.4 What is the likely/perceived role of the public plant breeding sector in fulfilling these needs?

The question regarding the role of the public plant breeding sector has been discussed during the interviews with the experts and also during the workshop that took place on 11 April 2012. The main conclusions are discussed below.

**Public sector agricultural research in general and public plant breeding research in particular has seen a reduction of activities for the last 30 years. This trend is more pronounced in the former EU 15 MS than in the new and candidates EU MS where there still are found public institutes that can be considered leading breeding actors (IHAR in Poland, Novi Sad in Serbia, INCDA-FUNDULEA in Romania)**. In contrast, private sector plant breeding investment has grown dramatically. Varietal protection and globalisation of the plant breeding schemes are additional reasons for the shift of balance of plant breeding activity from the public to the private sector.

This shift did materialise over a period of 30-40 years and not suddenly. It can also be observed that that shift is more pronounced for conventional (applied) plant breeding and that public budgets have moved to support upstream research (basic research, genomics and pre-breeding activities). Several arguments for public sector investment in plant breeding have been mentioned by experts contacted to date as follows:

- Scientific research in genomics and basic research is a "public good" as it is benefiting the society as a whole. It may complement the private research and give access to results to all SME's that have not the resources nor the capacities and expertise to engage in this type of research;
- Public plant breeding should complement private breeding for breeding (germplasm development and variety development) new traits of interest (e.g. traits regarding the respect of the environment) and for breeding on orphan crops (crops that private breeders are not investing in any longer as the costs of breeding are too high in regard to the possible return on investment);
- As in the past, public plant breeding can initiate the take-off of private breeding efforts for crops/traits combinations that are not considered by the private sector to date (e.g. silage maize breeding has been initiated by the French (INRA) and German (University of Hohenheim) public breeders before shifting to the private sector).

As an outcome of the workshop organised in the course of this study, the following areas have been considered as being the main focus of public applied plant breeding for the future:

- Improve minor crops neglected by the industry (e.g. field peas). For minor crops and for so called "non-cash" crops, private companies, especially SMEs, do not have sufficient resources to develop strong breeding programmes. Here, public breeding can play a major role moving them upstream in the research pipeline, to foster varietal development and the competitiveness of the breeding sector, including pre-breeding and conservation of varieties in gene banks;
- Increasing public sector commitment to germplasm preservation and development. For example, in the face of climate change and to meet the demands of a growing population, there is a strong need to continually obtain new varieties with improved characteristics. It is therefore important to enrich the genetic base of plant breeding. Genetic resources such as landraces are the basis for this, but it is a time-consuming and expensive procedure to introduce and validate new genetic traits into adapted plant material that can be used by plant breeding companies for further variety breeding;
- Refining and testing methodologies for variety testing. Climate change is not only a challenge for agricultural practices; it will also have a huge impact on seed companies. The need for greater flexibility in varietal development, in order to adapt to climate change, will increasingly be addressed by developing different germplasm in different locations. Public breeding will therefore have a direct role to play in developing and improving germplasm as a basis for competitiveness of a diverse seed industry which produces locally adapted varieties, for instance by fostering networks of experimental testing stations in different growing zones and climatic conditions.

- Enhanced technology transfer. Time-to-market for a new variety can take on average between 10-12 years. The use of new techniques, as well as the development of pioneering techniques, is essential to speed up the breeding cycles. In addition, the greater integration of new tools, such as new techniques for phenotyping plants as well as use of bioinformatics and data management systems, will be crucial. Public breeding can play a decisive role in this respect;
- Evaluate new plant breeding approaches (participatory breeding). PPB is defined as a form of plant breeding in which farmers, as well as other stakeholders, such as extension staff, seed producers, traders, NGOs, etc., participate in the development of a new variety. The objective is to produce varieties, which are adapted not only to the physical but also to the socio-economic environment in which they are utilized (Ceccarelli and Grando, 2007). At the European level, it has to be noticed the creation in 2012 of the European Coordination for farmers' seed, which constitutes a network of the different national networks. The current members are: Réseau Semences Paysannes (France), Rete Semi Rurali (Italy), Red de Semillas (Spain), Pro Species Rara (Switzerland), Arche Noah (Austria), Scottish Crofting Federation (UK). The creation of the European coordination was helped by a European project: Farmer's Seeds Project - Best Practices in Sustainable Agriculture and Food Sovereignty[25] (funded by the UE commission for 36 months, 1,300 K Euros with Italy, France, Scotland, Romania, Hungary, Senegal and Tunisia, 2009-2011).
- Educate and train plant breeders. The European Seed Association (ESA) recognises that there is a strong need for highly specialised plant breeders that are familiar with traditional as well as new breeding techniques, and having an increasingly multidisciplinary set of skills. Public plant research and breeding institutes, in partnership with private companies, can play a major role in developing and fostering the necessary skills-base for breeding and varietal development.

Literature review shows that there is a large consensus on the future role of public plant breeding activities to the exception of participatory plant breeding (PPB). The next chapters of this report do not consider PPB as no data related to the actual efforts have been compiled to date. Instead, we present an introduction of PPB objectives and list the main current initiatives under Annex 2.

## 3.5 Needs that are not sufficiently covered by the private sector?

Plant breeding is subject to top confidentiality. Private breeders are not used to disclose what they are breeding for. Research activities are not protected against possible stealing of varieties and numerous examples have showed that misuse of genetic material did happen in the past[26].

Therefore, the analysis of crop/trait combinations that are not sufficiently covered by the private sector has been made based on perceptions of experts and of national registration officers that have been met during the study rather than on hard data. Table 6 presents likely objectives under breeders consideration when the table below assesses whether or not enough efforts are being devoted to deliver a trait. A given trait can be considered as a priority but efforts may not be seen as sufficient to fulfil the objectives of the bio-based economy strategy 2020 and vice and versa. Eventually the following table only addresses private efforts and do not include public ones.

25 (http://www.farmerseeds.org/ ) 'Farmer's Seeds - Best Practices in sustainable Agriculture and Food Sovereignty: development of an inclusive approach in the Fight against Poverty' - DCI NSA ED/2009/201-955; NSA: Non-state actors and local authorities in development.

26 J. Grall, B. Roger Levy. 1985. La guerre des semences. Quelles moissons, quelles sociétés. Fayard. 410 p.

## Table 7 – Likely crop/traits combinations not or not sufficiently covered by the private sector

| Business objective | | Breeding needs | | Cereals | | | Oilseeds | | | Fodder plants | | | Fruits | | Vegetables | | | Industrial crops | | | Others | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Winter wheat | Maize | Triticale | Sunflower | Winter OSR | Soybean | All gramineae | All legumes | Wine | Apple | Potatoes | All Brassicaeae | All tomatoes | All lettuces | Sugar beet | Hop | Cotton | Miscanthus | Jatropha | Poplar | Others |
| Food and feed (coton included) | Food security (agronomic criteria) | Crop productivity | Yield | | | | | | | | | | | | | | | | | | | | | |
| | | | Yield stability | | | | | | | | | | | | | | | | | | | | | |
| | | Resistance to biotic stress | Virus | | | | | | | | | | | | | | | | | | | | | |
| | | | Fungus and other diseases | | | | | | | | | | | | | | | | | | | | | |
| | | | Nematodes | | | | | | | | | | | | | | | | | | | | | |
| | | | Insects | | | | | | | | | | | | | | | | | | | | | |
| | | | Bacteria | | | | | | | | | | | | | | | | | | | | | |
| | | Resistance to abiotic stress | Salt | | | | | | | | | | | | | | | | | | | | | |
| | | | Drought | | | | | | | | | | | | | | | | | | | | | |
| | | | Metal | | | | | | | | | | | | | | | | | | | | | |
| | | | Cold & heat | | | | | | | | | | | | | | | | | | | | | |
| | Food safety & plant health | Suppression of negative composants | Mycotoxin free | | | | | | | | | | | | | | | | | | | | | |
| | | | Heavy metals free | | | | | | | | | | | | | | | | | | | | | |
| | | | Allergenic free | | | | | | | | | | | | | | | | | | | | | |
| | | | Other natural toxic substances free | | | | | | | | | | | | | | | | | | | | | |
| | | Nutritional improvement | Oil profile | | | | | | | | | | | | | | | | | | | | | |
| | | | Vitamins | | | | | | | | | | | | | | | | | | | | | |
| | | | Flavonoids | | | | | | | | | | | | | | | | | | | | | |
| | | | Carotenoids | | | | | | | | | | | | | | | | | | | | | |
| | | | Others | | | | | | | | | | | | | | | | | | | | | |
| | Respect of the environment | Less dependent in input factors | PPP | | | | | | | | | | | | | | | | | | | | | |
| | | | Fertilisers | | | | | | | | | | | | | | | | | | | | | |
| | | | Water | | | | | | | | | | | | | | | | | | | | | |
| | | | Energy | | | | | | | | | | | | | | | | | | | | | |
| | | Phytoremediation | | | | | | | | | | | | | | | | | | | | | | |
| | Feed | Agronomic criteria | See food security and environmental criteria | See above | | | | | | | | | | | | | | | | | | | | |
| | | Environmental criteria | | | | | | | | | | | | | | | | | | | | | | |
| | | Improved feed composition | Palatability | | | | | | | | | | | | | | | | | | | | | |
| | | | Energy content | | | | | | | | | | | | | | | | | | | | | |
| | | | Protein content | | | | | | | | | | | | | | | | | | | | | |
| | | | Digestibility | | | | | | | | | | | | | | | | | | | | | |
| Non food and feed | Bio energy (First generation) | Agronomic criteria | See food security and environmental criteria | See above | | | | | | | | | | | | | | | | | | | | |
| | | Environmental criteria | | | | | | | | | | | | | | | | | | | | | | |
| | Bio energy (second gneration) | Agronomic criteria | See food security and environmental criteria | See above | | | | | | | | | | | | | | | | | | | | |
| | | Environmental criteria | | | | | | | | | | | | | | | | | | | | | | |
| | | Specific criteria (improved characteristics | Improved net energy balance | | | | | | | | | | | | | | | | | | | | | |
| | | | Improved raw material composition | | | | | | | | | | | | | | | | | | | | | |
| | | | Improved raw material for process optimisation | | | | | | | | | | | | | | | | | | | | | |
| | | Domestication | | | | | | | | | | | | | | | | | | | | | | |
| | Bio chemical | Target products | PMP | | | | | | | | | | | | | | | | | | | | | |
| | | | Specialty chemicals & enzymes | | | | | | | | | | | | | | | | | | | | | |
| | | | Plant derived oils | | | | | | | | | | | | | | | | | | | | | |
| | | | Polymers | | | | | | | | | | | | | | | | | | | | | |
| | | | Fibres | | | | | | | | | | | | | | | | | | | | | |
| | | Domestication | | | | | | | | | | | | | | | | | | | | | | |

*Source: Compiled by Arcadia International*
*Note: In black: Not Applicable*

Crop/trait combination partly covered by the private sector

Crop/trait combination not sufficiently covered by the private sector

# 4. PUBLIC PLANT BREEDING CAPACITIES IN THE EU 27 MS

This chapter of the report maps the development of the EU 27 MS public breeding sector (applied breeding resulting in cultivation of new varieties) in the last decades and presents the capacities and resources of the public plant breeding sector (including public/private co-operations).

An introductory section describes the evolution of the public breeding sector (with the main focus on applied plant breeding) in the EU 27 MS in comparison to the private breeding sector and in the context of the global situation. This introduction also includes a qualitative benchmarking analysis with Third Countries for a limited number of country/crop combinations.

## 4.1 Evolution of the applied public plant breeding sector in the last decades

### *4.1.1 Plant breeding: from an art to a science*

In its primitive form, plant breeding started with agriculture, when people of primitive cultures switched from a lifestyle of hunter-gatherers to sedentary producers of selected plants and animals. Humans discovered the most basic technique that is "selection" meaning the art of discriminating among biological variation in a population to identify and pick-up the most desirable plants.

Plant breeding remained an art for centuries and was solely based on the intuition, skill, and judgment of the operator (the breeder's eye).

Plant breeding started to turn to be a science based on the findings of Mendel in 1865. The post-Mendelian period (also called modern plant breeding) depends on the principles of genetics, the science of heredity to which Gregor Mendel made some of its fundamental contributions.

One of the earliest applications of genetics to plant breeding was made by the Danish botanist, Wilhelm Johannsen in 1903. In 1919, D.F. Jones took the idea of a single cross further by proposing the double-cross concept, which made the commercial production of hybrid maize seed economically viable. Mutagenesis became a breeding technique in the 1920s and mutation breeding accelerated after World War II.

In 1944, DNA was discovered to be the genetic material. Scientists then began to understand the molecular basis of heredity. New tools (molecular tools) are being developed to facilitate plant breeding to facilitate transfer of genes from one parent to another.

The following step, specifically called genetic engineering, enable to circumvent the sexual process to transfer genes from virtually any organism to another. The products of the application of this technology are generally called genetically modified or transgenic products and are hosted under the umbrella name of plant biotechnology.

Louwaars et al.[27] summarise this evolution by mentioning that "*until the 1980s breeding was merely an empirical activity were breeders, on the basis of much knowledge and experience about traits of the reproductive material made crosses and selected the most suitable plants.[...]This meant that the development of a new variety took from 10 to 24 years, depending on the species. The development period decreased to 4 to 11 years over the last 30 years by application of a wide range of new biotechnological methods, such as tissue culture, mutation breeding, DNA technologies, molecular breeding, etc...*". Regular and constant technology improvement is a key characteristic of the plant breeding sector that made that many authors are considering that plant breeding is currently moving from an art to a science.

[27] Louwaars et *al.*.2009. Breeding business – the future of plant breeding in the light of development and patent rights and plant breeder's right. Report from the Centre for Genetic Resources, the Netherlands.

### *4.1.2 The evolution of the plant breeding sector at global level*

**Unill end of the World War II, almost all plant breeding activities took place in public institutes, and almost all plant breeders received their scientific education in public universities. Over time, plant breeding activities shifted gradually to the private sector.**

The main factors that affected this privatisation of plant breeding efforts can be summarised as follows.

#### 4.1.2.1 COMMERCIALISATION OF AGRICULTURE

In most industrialised countries, as agriculture became more and more commercial, private firms increased their investment in, first, marketing seed varieties; and secondly, creating new varieties instead of buying them from public institutes. As a result, many countries have seen a rapid growth in the number of private seed companies, greater investment in plant breeding research, and greater availability of improved cultivars (Morris and Ekasingh, 2002).

These increased investments led to the modernisation of plant breeding techniques. Traditionally, return of plant breeding was rather low (return on investment estimated at less than 10%). Therefore the strategy and one the major objectives of the seed companies led to create economic value in this area mainly based on the introduction of hybridization and new plant breeding techniques.

The seed industry developed due to the introduction of hybrids, especially hybrid maize in North America, hybrid sugar beet in Europe, and hybrid vegetables in South-East Asia. Of the US $ 27 billion market in commercial seed at present, hybrids account for approximately 40-50 % of sales, and for most of the profit.

In North America and Europe the hybrid seed industry grew from regionally based family businesses. The profitability of hybrids far outstripped that of non-hybrid open-pollinated seeds. This led to the eventual consolidation of the industry and the dominance of several key companies with particular crops. The appeal of hybrids for the seed industry is obvious: when double-cross maize hybrids were first commercialized in the USA in the early 1930s, they were priced at approximately 10 to 12 times the price of commercial grain. With the introduction of single crosses in the 1960s, hybrid maize seed prices jumped to between 20 and 25 times the commodity price.

Based on this evolution, arguments in favour of using public funds to support plant breeding, and more generally agricultural research, have become difficult to sustain and therefore a shift of plant breeding activities to the private sector has occured. The process has been crop species and region specific. In many developing countries, this shift has been slower as their type of agri-business is less appealing to the private sector.

#### 4.1.2.2 DEVELOPMENT AND MATURATION OF THE SEED BUSINESSES

Over the 1950-1980 period, seed businesses developed and seed industries matured based on the introduction of the life sciences concept, protection of intellectual properties and consolidation of the sector.

*Introduction of the life science concept*

In the 1970s the high margins obtained from hybrid crops attracted the interest of agrochemical companies, hoping to exploit possible synergies with the seed business and their own line of business, while looking for diversification. The acquisition of *Northrup King* (USA) by *Sandoz* (Switzerland), of *Funk Seeds* (USA) by *Ciba-Geigy* (Switzerland), of *Nickerson* (USA) by *Shell* (UK/the Netherlands), and of *Asgrow* (USA) by *Upjohn* (USA) happened during this period.

In the 1980s agrochemical companies engaged in biotechnology research began to acquire seed companies. They did so realising that seed would be the primary delivery system for their new technologies, particularly biotechnology. They believed that delivering and capturing value from new input and output traits required control over the distribution channel. This brought companies such as *Dupont* (USA), *Elf Aquitaine* (Sanofi) (France), *ICI*

(USA), *Monsanto* (USA), *Rohm & Haas* (USA), and *Unilever* (the Netherlands) into the seed business. Their strategy was to capture margins along the agribusiness value chain from the laboratory to the field.

This strategy did not work for all new entrants. Firstly, the time required to convert the early new technologies into useful products took much longer than originally envisioned. Secondly, there was a divergence between the entrepreneurial management style of the comparatively smaller seed companies, and the hierarchical style of most large chemical companies. Thirdly, the learning curve was longer and more complex than expected and led to poor financial performance. Finally, unlike chemicals, seed cannot be marketed globally, but in agro-climatic regions similar to the locations where it was developed (mass marketing vs. targeted marketing). As a result, companies such as *Shell, Rohm & Haas, Sanofi, Upjohn*, began to divest themselves of their seed and biotech businesses in the 1990s.

A French book entitled “La guerre des semences” written (year??) by J.Grall ans B. Roger Lévy summarise this period and highlights the strategies taken by the different actors that can be grouped in groups as follows:

- Monsanto turned from a chemical company to a seed company in 20 years’ time with a very aggressive strategy to acquire. It is one of few companies that has not changed its strategy during the last 30 years;
- Traditional chemical companies that invested in seed later than Monsanto and limited their investment (e.g. DuPont buying Pioneer);
- Traditional chemical companies (many of the European: Bayer, BASF, Aventis, Syngenta) that took more than 10 years to finalise their overall strategy (due to the fact that GM products could not be introduced in the EU);
- Traditional regional seed companies that invested in modern plant breeding techniques via public/private partnerships (e.g. Limagrain via Genoplante, KWS via GABI);
- Finally, companies that do not work on major global hybrid crops and that made the decision not to engage in the biotech game, while focusing on conventional breeding using molecular tools (except genetic engineering).

*Consolidation of the seed sector*

The emergence of biotechnology for agriculture in the 1980s led to the complete reorganisation of the seed sector. Today leading seed groups are largely owned or allied with the world leading chemical/plant protection companies as it was highlighted in the previous paragraph. Consolidation through mergers and acquisitions took place for the major field crops, and it is not yet complete in the vegetable sector.

In 1996, the top 10 seed companies represented about 37% of the worldwide market; in 2004, the top 10 accounted for nearly 50% of the certified seed market worldwide (ETC 2006 report) Monsanto, the actual market leader was not present in the top 10 I 1996. The European seed sector is characterised by a large segmentation of actors (from national SMEs involved only in cereals or ornamentals to international companies with a multi-crop approach).

In 2008, ESA statistics indicated that 21 companies, out of 42 ESA individual members, have an annual turnover of less than 50 million Euros while the three largest companies have a turnover of more than 250 million Euros each. The EU seed sector continues to be made of a majority of small and medium sized companies.

In the EU 15 MS the number of employees in the private sector amounts to around 30,000. Staff involved in plant breeding is estimated at 5,000, distributed in more than 600 breeding stations.

*Intellectual Property Right (IPR) driven restructuring of the seed industry (biotech breeding)*

Introduction and cultivation of GM crops hastened the convergence of the agricultural biotechnology, seed and chemical industries and changed the cost structure of the traditional seed business and product pricing. Therefore, attempts have been made to separate the value of technology from the value of the seed in the form of a ‘technology premium’ to be paid by farmers when they purchase a product improved by a biotechnology (Monsanto).

The technology used for the transgenic seeds that are currently marketed can be broadly divided into two major groups: genes and enabling technologies. Genes encode proteins that are responsible for the (transgenic) trait. The important enabling technologies include plant transformation systems, selectable markers, gene expression techniques, and the so-called gene 'silencing' technologies. Plant transformation systems are employed to insert specific genes into plant cells.

Because most transgenic plant products contain or have been developed using several biotechnologies, it is simple for a company owning the IPR of one such technology to block the development of a product. As a result, in order to maximize the value of recovery, minimize the threat of litigation, and secure access to the technology, several strategic 'partnerships' were formed in 1995 and 1996. For example, technology IPR issues drove to a large extent Monsanto's acquisition of 49.9 % of Calgene (USA), 45 % of Dekalb (USA) and 100 % of Agracetus (USA). The acquisition of Plant Genetic Systems (PGS, Belgium) by AgrEvo GmbH (Part of Hoescht in Germany) in August 1996 for approximately 600 million Euros is perhaps a noteworthy strategic partnership. Both Monsanto and AgrEvo invested heavily to gain access to the technologies that were subject to IPRs held by PGS and others.

Since most transgenic seeds either contain several technologies or depend on them for their development, IPR issues have become an important competitive element in the seed industry. Even in cases where a technology is novel and patented, it may be dependent on earlier developments, thus even the inventor cannot freely use it. Therefore, from the first transgenic seeds a rather complicated IPR pedigree emerges. At issue is the so-called 'freedom to operate', which can be defined as legal access to all the technologies required for launching a product.

The restructuring of the seed industry that is now nearly complete has being driven by technology and IPR /patent issues. The winners in this process are those companies that are able to deal with the complexities of IPR and bring their transgenic products into the market. To date, it is recognised that the major winner globally, for transgenic crops, is Monsanto.

*Globalisation: from local breeding to global breeding*

Consolidation and globalisation has tremendously helped breeders to reduce the breeding cycle especially for spring crops (e.g. maize, sunflower, canola) and vegetable crops. By using winter nurseries in the southern hemisphere, breeding times have been shortened (from 7-10 years on average to 3-4 years) and in turn costs of breeding a new variety have also been reduced significantly. Twenty years ago, it took 4-5 years to backcross a given trait in a variety. Today with the use of different winter nurseries and the support of molecular tools, backcrossing can be completed in only 1 year (3 cycles per year). This optimisation though is not helping winter crops (winter cereals and winter oil seed rape) and "heavy crops" (those crops whose seed is too heavy to be transported across continents) (e.g. wheat and cereals).

### 4.1.3 The evolution of the public plant breeding sector at global level

The study focuses on the analysis of the evolution of the public plant breeding sector in the EU. This evolution has to be put in the perspective of the evolution at global level. Do we observe the same trends at the global level or do we have a unique situation in the EU compared to the major international agricultural areas?

In order to approach this comparison, the following case studies based on country and crop combinations have been considered: 1) Australia and wheat, 2) Brazil and sorghum, 3) Chile and potato, 4) the United States and maize, and 5) a group of Asian rice-growing countries (Philippines, Indonesia and Vietnam)[28]. This selection of combinations considers a mixture of developed and developing countries, in different regions, plus crops whose importance is critical for the economies of those countries. Another factor taken into account in this selection was the type of institution involved, i.e. national and international.

[28] Methodology regarding this data collection is presented in Annex

#### 4.1.3.1 AUSTRALIA AND WHEAT

The Grains Research and Development Corporation of the Australian Government (GRDC) is responsible for planning, investing and overseeing research and development, delivering improvements in production, sustainability and profitability across the Australian grains industry. In the past, GRDC provided competitive funding and the Universities and the State Department of Agriculture did the breeding. In early 2000, a national initiative was launched to re-focus and re-position Australia's wheat-breeding efforts in a rapidly changing, highly competitive global economy, thus breeding programs were privatized. GRDC provided transition funding to privatization but now it does no longer fund breeding. Instead, GRDC funds pre-breeding public sector research that can be used by the private companies.

Three main companies are involved in wheat breeding: Australian Grain Technologies Pty Ltd, InterGrain Pty Ltd and LongReach Plant Breeders. These companies compete for market share and rely on income from End Point Royalties (EPR is a standardized agreement to license new varieties to growers by which the royalty is paid on delivery of the grain, not on sale of the seed). The EPR represents a performance-based equitable return to the breeder/owner for successful crop breeding and shares the risk between the breeder and the grower. This brings much more money into the system and breeding companies are self-supporting. The national wheat-breeding companies and a smaller specialist one (HRZ Wheats Pty Ltd) aim to rapidly develop and deliver varieties with improved characteristics to Australian growers.

The Australian wheat breeding companies fulfil growers' needs countrywide in terms of breeding expertise, access to technology, germplasm resources, seed production and commercialization capacity, spanning the complete chain from geneticists to end-users. Each company targets the development of wheat varieties for specific agro-ecological conditions and simultaneously endeavours to excel in particular niches, be it due to its germplasm base or the breeding objectives. GRDC invests in pre-breeding research (in 2009-10 about $22 million of levy money for wheat and barley) discovering and validating new genes and traits and delivers these traits non-exclusively to the commercial wheat breeding programs. GRDC also sponsors platforms such as the Australian Winter Cereals Pre-Breeders Alliance to ensure closer links between pre-breeding researchers and the commercial wheat breeding companies, and it funds the national variety trials.

#### 4.1.3.2 BRAZIL AND SORGHUM

The Brazilian Agriculture Research Corporation, Embrapa is the R&D division of the Ministry of Agriculture of Brazil. Out of the 44 research centers of Embrapa, one focuses on maize, sorghum and millet research, development and innovation at the national level. The sorghum improvement program at Embrapa began 40 years ago. Today the team is composed of about 70 scientists trained at the PhD level and about 250 research and administrative support staff of which around 25 scientist man years are dedicated to sorghum. This includes five sorghum breeders developing grain, forage and bio-energy (sweet sorghum and biomass) varieties and hybrids. Three of the breeders were contracted within the last four years and, out of these, two were an increase in the research staff size. Sorghum breeding at Embrapa spends 75% of the effort in developing new cultivars and about 25% in basic upstream research, for which it collaborates with several international institutions. Most research scientists including pathologists, entomologists, molecular biologists, soil scientists, and other areas of research, support the development of new cultivars.

Embrapa has been a world leader in advancing tolerance to aluminum toxicity and improved phosphorus acquisition efficiency as well as in improved productivity of ethanol and energy production with sweet and biomass sorghums. Embrapa releases about two new sorghum cultivars per year and it invests over 2 million US dollars per year in developing and releasing sorghum cultivars. Some of the cultivars are released for seed production by the private sector, which represent 33% of the area planted to grain sorghum, 44% of the area planted to forage sorghum, and nearly 100% of the area planted with sweet sorghum for ethanol production. Principal constraints for the sorghum improvement program are field and laboratory support personnel and the R&D budget, especially for traveling to accompany off station trials across Brazil and to acquire modern plot equipment to reduce field labour.

In the near future, 10 – 20 years, the Embrapa Sorghum Improvement Program will continue to receive significant financial support from the federal government. However, Embrapa looks forward to increasing its interaction with the private sector for joint development of elite lines and germplasm; it will also be releasing breeding lines that the private sector may use in combination with proprietary lines to develop hybrids. The domestic private sector would like Embrapa to implement partnerships that allow it to become more competitive, for example by accessing germplasm and genetic resources developed by Embrapa, while Embrapa mainly concentrates in upstream research, new breeding methodologies and semi-finished products that can be transferred to them. In twenty or more years the development and use of sorghum cultivars might be entirely in the hands of the private sector.

#### 4.1.3.3 CHILE AND POTATO

The Instituto de Investigaciones Agropecuarias (INIA, *Agricultural Research Institute*) of Chile has the mandate for potato breeding since 1974. Nine commercial varieties have been released from 1983 to 2011, and out of those, four varieties represent about 55% of the Chilean market.

In terms of human resources, until 2010 breeding work relied on two full-time breeders, one dedicated to testing advanced materials in the central zone and the other dedicated to crosses and assays in the south. There are also one molecular breeder, two laboratory technicians (one biochemist and one tissue culture specialist), two field technicians, seven field workers and four part-time research agronomists. For the last ten years progress has relied heavily on competitive funds. Core funds (50% of total resources) from the Ministry of Agriculture are to pay salaries to permanent employees. The other 50% comes via projects obtained through competitive calls. These projects last 3-5 years, insufficient to support a breeding program; thus crop breeding must be integrated in other projects with focus on agronomy and molecular biology, among others. In addition to short-term and uncertain funding, competitive projects require the participation of the private sector (at least 20%), a situation that often results in non-viable projects because the private sector is not always ready to chip in. Projects are rarely initiated without the participation of the private sector.In 2008, INIA was awarded a highly competitive project (5 years, 60% government and 40% private sector) through a new funding instrument named 'Consorcio Tecnológico de Investigacion Empresarial' (*Technological Consortium of Corporate Research*). There is also a Potato Consortium with the participation of 15 private entities and two technological entities (INIA and Universidad de Los Lagos). The Potato Consortium is a for-profit corporation that must result in technological production, such as variety royalties. This and other services are promising avenues, in spite of the fact that international regulations (e.g. UPOV 78) set limits in royalties collection mechanisms that could be implemented[29].

INIA extensively collaborates with the International Potato Center (CIP) in different projects: through the Red LatinPapa, a network funded by Spain; a project based on climate change to develop varieties tolerant to drought; a project about native potato funded by CONICYT-Chile; germplasm exchange for resistance to diseases (late blight, viruses); and evaluation of Chilean varieties through CIP regional offices. INIA's breeders closely collaborate with breeders from other INIA in South America such as INTA of Argentina, INIA of Uruguay and EMBRAPA in Brazil --with which there are exchanges, training and visits, with several universities in the USA (Cornell University, Dakota University, University of Wisconsin, and University of Pennsylvania) and with the University of Wageningen in the Netherlands. Moreover, INIA collaborates with the private, public and international sectors in different ways: through agreements to represent INIA varieties in a particular market, to develop varieties specifically for that market with traits decided by a given company, to evaluate Chilean material in other countries as a step towards the introduction of varieties in their productive systems, for the joint development of varieties with national institutions in other countries and with foreign private sector for the evaluation of varieties and advanced germplasm.

In the future, efforts will continue towards the internationalization of the program, that is expanding evaluation of materials in diverse latitudes. Market trends include a diversity of coloured flesh potatoes and resistance to late blight. It is expected that knowledge of the potato genome sequence will support the search for genes of novel

[29] More information on http://www.upov.int/about/en/pdf/353_upov_report.pdf

traits and there is willingness to ensure that all biotechnology projects are aligned with breeding needs, not just stand alone research.

#### 4.1.3.4 THE UNITED STATES AND MAIZE/SOYBEAN

Only partial information about conventional crop breeding U.S.A. programs for variety release is available. Most research projects include some breeding components to boost funding potential, but in reality their connection to variety release is loose. The USA public sector releases very few maize varieties and very few soybeans, yet there is more active involvement in breeding fruits, vegetables and small grains. It does release some maize inbred varieties that private companies take up and use. Most of soybean varieties originate in the private sector too. Basically, for these crops the public sector focuses on pre-breeding research using germplasm from diverse genepools that can be accessed through international collaboration. The large private sector precisely demands that these activities and type of collaboration continue. Partnerships with the private sector and with the international sector are not kept in records, so information lies with particular research groups. A white paper produced in 2008 (Strategic Research, Education and Policy Goals for Seed and Crop Improvement. Presented at the American Seed Research Summit at Chicago, IL by the National Council of Commercial Plant Breeders) is still a good summary of current thinking about public and private sector partnerships, the challenges collaboration faces and new models of collaboration that might be necessary henceforward. Notwithstanding the situation with field crops, there is growing demand and support from organic growers that is evident for orchard or vegetable crops. The use of new tools for breeding these crops allow focus in niche markets with specialty traits, beyond broad adaptation, and thus new areas for expansion.

U.S. public sector breeding research is done at the U.S. Department of Agriculture and universities countrywide. During the last ten years, there has been a clear decline in human capacity, i.e. US citizens preparing to become plant breeders, which is a situation of concern. The same decline affects state funding and that from private donors. Moreover, large funding gaps exist between major and minor states (based on congressman hatching funding opportunities). This was the basis to found the National Association of Plant Breeders (NAPB). The NAPB started as an initiative of the Plant Breeding Coordinating Committee (PBCC), which in turn was born in 2005. The PBCC is a forum for leadership, regarding issues, problems, and opportunities of long-term strategic importance to the contribution of plant breeding to national goals. The NAPB is the outreach group that represents plant breeders in federal, state, commercial and non-governmental organizations. The mission of the NAPB is to strengthen capacities for U.S. plant breeding research, technology, education, and public awareness to meet needs for plants on which the nation and the world rely.

Two main constraints for breeding are the availability of funds and the lack or low public understanding. Since the mid-1990s, there has been criticism in the U.S.A. about the real need for public sector plant breeding. Several positions from several actors have clearly mentioned that public funding should be dedicated to more upstream research (e.g. genomic) rather than developing varieties that should be the solely responsibility of the private sector. Involved issues have been the subject of discussions between multi-state plant breeders and the federal government (USDA), and also between the USDA and the NAPB.

#### 4.1.3.5 RICE IN ASIA (INDONESIA, PHILIPPINES AND VIETNAM)

The International Rice Research Institute (IRRI) is a member of the CGIAR Consortium, a non-for-profit independent research and training organization. Since 1960, IRRI develops rice varieties and rice crop management techniques to help rice-producing countries grow more and better rice in an environmentally sustainable way. To conduct its work IRRI collaborates with partners in the public and private sectors. Essential for this collaboration is INGER, a global model for the exchange, evaluation, release and use of genetic resources, that holds a repository of detailed information on the genetic make-up of rice varieties. IRRI, through INGER, produces germplasm that is made freely available to breeding programs in partner countries. This germplasm is crossed or combined with traditional or popular varieties. The breeding process continues over several years until superior lines are identified in trials and the appropriate country committee for varietal release assesses its suitability for release as a commercial variety. Then, seed is produced for distribution and promotion to farmers.

Three examples of collaboration with IRRI are described: Indonesia, the Philippines and Vietnam. The information henceforth comes from the IRRI website and the ACIAR Impact Assessment Series Report No. 74 published in 2011 ("International Rice Research Institute's contribution to rice varietal yield improvement in South-East Asia" by John P. Brennan and Arelene Malabayabas.)

*Indonesia*

Collaboration between the government of Indonesia and IRRI began on December 1972. Recent past agreements covered research and human resource development, genetic evaluation and utilization, the management of rice genetic resources, forecasting pest and disease epidemics, improving soil quality, and technology generation and promotion. In early 2011 a four-year agenda for IRRI and Indonesia's partnership was hatched. Indonesian institutions involved in scientific development of rice varieties and technologies are: (a) the Indonesian Institute of Science; (b) the National Atomic Energy Agency; (c) Bogor Agricultural University; (d) Gadjah Mada University; and (e) the Indonesian Center for Agricultural Biotechnology and Genetic Resources Research and Development. Key Indonesian institutions involved directly in rice research and in developing and releasing improved rice varieties for farmers in Indonesia are: Indonesian Center for Rice Research (ICRR) that operates the breeding programs, Indonesian Center for Food Crops Research and Development (ICFORD) and Committee for Variety Release.

Initially, varieties were released by IRRI itself and now they are commonly released by the Indonesian Agency for Agricultural Research and Development (IAARD). In spite of this, the link between varieties released in Indonesia and IRRI has remained strong; for example, of the 83 varieties released in the decade to 2009, 75 were connected to IRRI in some way and 17 were classified as 100% IRRI. IRRI has also played a key role in the development of hybrid rice varieties for tropical conditions.

*The Philippines*

IRRI's partnership with the Philippines began on September 1959 when the proposal to establish IRRI in the country was approved. The Philippines have contributed more than 5 million US dollars since IRRI's inception, out of which 1.409.184 US dollars correspond to 2000-2009. IRRI works with Philippine partners in areas of technology transfer, water-saving technologies, pest management, nutrient management, real-time crop monitoring, and capacity building. Recently, a mobile communication-based nutrient management technology was launched for Filipino farmers.

The key Filipino institutions involved in rice research and in developing improved varieties are: Philippine Rice Research Institute (PhilRice, established in 1985), University of the Philippines Los Baños (UPLB) and National Seed Quality Control Services (NSQCS). Breeding programs are operated by PhilRice, UPLB and the Department of Agriculture (Bureau of Plant Industry). In more recent years, private companies have also bred new varieties. Breeders' and foundation seeds of approved varieties are distributed to members of the National Rice Seed Production Network (SeedNet) for multiplication and accessibility to seed growers and farmers.

IRRI lines were initially released directly as varieties. In 1975, IRRI decided to let national programs release the IRRI-bred lines as varieties. In 1988, PhilRice assumed the responsibility for testing improved germplasm. The number of variety releases has grown with time and it was 83 in the 2000s, out of which 40% were IRRI crosses and 52 were connected to IRRI in some way. In spite of this, there is a trend of decreasing IRRI contribution to the pedigrees of recently developed varieties in the Philippines.

*Vietnam*

IRRI and Vietnam have been partners since 1963 collaborating in the fields of rice breeding material exchange, rice varietal improvement, conservation of rice diversity, sustainable farming systems, resource management, and capacity building. Vietnam has contributed a total of 120,000 US dollars to IRRI's research agenda from 2002-2009. The challenges that need to be addressed in Vietnam for rice breeding are: pest and diseases - brown plant hopper (BPH), virus disease transmitted by BPH and bacterial blast; grain quality and stresses - drought, salinity and acid sulfate toxicity.

The Vietnamese key institutions involved in rice research are: Agricultural Genetics Institute (AGI), Cuu Long Delta Rice Research Institute (CLRRI), Field Crops Research Institute (FCRI) and National Centre for Plant and Fertilizer Testing (NCPFT). IRRI breeding lines with biotic and abiotic stress tolerance and resistance are used in the AGI breeding program to produce locally adapted varieties. NCPFT, seed companies/distributors, farmer groups/cooperatives and extension agencies are all involved in the varietal testing and development for farmers. Once a promising line is released as a new variety, the seed is given to the seed companies for multiplication.

In Vietnam, the rate of release of new varieties was especially high in the 1990s. In the 2000s, out of 68 rice varieties released, 12% were direct IRRI releases, while the use of IRRI lines as parents or as earlier ancestors was as high as 65% in the total number of varieties.

#### 4.1.3.6 CONCLUSIONS

**The evolution of plant breeding shows evident trends of change towards privatization (well developed countries and emerging economies) and towards self-reliance in developing countries. These trends go in parallel with diversion of research funds to different and new economic sectors leading to a reduction of funding for agricultural research.**

In Australia, about ten years ago wheat breeding was transferred to the national private sector that covers the needs of growers countrywide. In the United States, corn and soybean breeding of new varieties is in practice all in the hands of the private sector. Brazilian sorghum breeding has important support from the government, but the pressure is there to hand over variety development to the domestic private sector in the medium term. In Chile, potato breeding is still under the responsibility of the government but the involvement of the private sector is required in the form of funding for breeding projects to be approved, and agreements are in place for marketing Chilean varieties in several foreign countries. The case studies of rice breeding in South-East Asia, under the umbrella of IRRI, an international research organization, show that national breeding programs are more and more taking the lead, on one hand, and also that some privatization has started to occur (e.g. the Philippines) for variety development; this will surely increase with the production of hybrid rice. Also, there is private sector involvement in multiplication and commercialization.

Thus, privatization is happening not only with cross-pollinating crops, such as maize, but also with self-pollinating crops, supposedly unsuitable for the purposes of the private companies. For this to happen Australia devised the implementation of a system of End Point Royalties and Chile established a new funding instrument that assures greater and active participation of the private sector.

The indisputable very important role that remains for the public sector is pre-breeding with the introduction of genes and traits from untapped genetic resources into unfinished materials and the development of new breeding methods. This is in line with the current preference for upstream research - including genomics - in public institutions, a trend that certainly shifted funding away from conventional breeding for variety release. Last, the public sector may continue to be vital for breeding of specialty crops, targeting very particular niches, taking into account the expansion of organic agriculture, a type of private sector that still relies on the contribution of public research for its growth.

### *4.1.4 The evolution of the public plant breeding sector in the EU*

**Public plant breeding sectors held a strong position in the majority of EU 27 MS until the end of the 1970s before it started to decline**. In each of the major agricultural country, one or several institutes were key players in plant breeding activities before privatisation occurred.

Outstanding results from public breeders have been observed mainly in term of germplasm improvement but also in technology development. The two following examples illustrate contribution of the public sector in the development forage/silage maize in Northern Europe and in the actual evolution of the oilseed rape seed market from an open pollinated to a hybrid crop.

**The role of public plant breeding in the development of forage/silage maize in Northern Europe.**
Although maize was early recognized as an excellent forage plant soon after its introduction in Europe, during a long time it was only bred for grain traits. However, the first recommendations of maize varieties for specific forage use are probably those given in the French VILMORIN-ANDRIEUX catalogues as early as the second mid of the 19th century. The 1940 Dutch

variety list distinguished several types of maize varieties and was already recommending three varieties for silage use. Whereas US hybrids were introduced in Europe in the early 1950s, the significant extension of silage maize cropping began after the release of early flint x dent hybrids such as INRA258 (1958) and a little later Brillant DK202, Capella, LG11, and Blizzard G188 (between 1965 and 1975). The increase went on until 1990, with a decrease or stabilization following. The first generation of early European maize hybrids was mostly often based on crosses between flint Lacaune and dent Minnesota13 lines. The registration of Dea (1980) in France and a few years later Golda in Germany both illustrated tremendous changes in maize dent, and to a lesser extent flint, germplasm and marked the onset of a second era in European maize hybrid breeding. The average genetic improvement in whole plant yield was close to 0.10 t/ha.year during the period between 1958 and 1988, but reached 0.17 t/ha.year between 1986 and 2004. In early maize, highly significant improvements of stalk standability, stalk rot and lodging resistance have been achieved between 1950 and 2004 in Europe. Physiological changes associated to these improvements are at least delayed senescence of leaves and stems, higher grain filling rate, and higher stress tolerance. Conversely to agronomic value, a steady decline in the average cell wall digestibility of hybrids was observed since the 1950s, and maize of the next future have to give a better balance between agronomic and feeding value traits.
Several public plant breeders have contributed to the development and quality improvement of forage maize varieties. The first early flint x dent hybrid developed in Europe was most likely Goudster obtained in the Netherlands by Van den Eijnden (DOLSTRA and DE JONG, 1984), and it led to a first increase of maize area in northern Europe in the beginning of the 1950s (BUNTING, 1978). The early flint lines F7 and F2 were selfed in the French Lacaune landrace (PROMAÏS, 1999) by INRA in Clermont-Ferrand. During the period of 1957-1979, flint lines were mainly related to Lacaune F2 and F7 lines that were provided to private breeders via royalties' agreements and to the Spanish line EP1. Gelder Badisher Landmais germplasm was afterwards introduced and played an important role in the development of early flint lines. To a lesser extent, Swiss line CH10 (Linth) and German line Du101 (Umkirch) were also used in second cycle line breeding. During the period 1958 - 1975, most of important hybrids used for silage in France, Germany, and probably even in the Netherlands, had F7 x F2 as one parental hybrid.
This example demonstrated the key role that public plant breeding has played in the development of forage maize in the EU.

*Source: Compiled by Arcadia International*

**The role of public plant breeding in the development of hybrid cultivars in oilseed rape in the EU.**
Hybrid winter oilseed rape (*Brassica napus*) cultivars enjoy a 15 to 20% yield advantage over conventional varieties based on the expression of hybrid vigour (Brandle & McVetty 1989). A number of methods have been developed to maintain genetic male sterility, in order to enable a commercial hybrid seed production. One of the most recent of these is the Ogu-INRA cytoplasmic male sterility (CMS) system, in which the male sterile parent is homozygous recessive for the fertility restorer gene (rfrf) and contains a male-sterile cytoplasm (S), while the restorer line is genetically RfRf (Delourme et al. 1998). The CMS trait was obtained from a protoplast fusion between an oilseed rape cultivar and a CMS line carrying radish (*Raphanus sativus*) cytoplasm (Pelletier et al. 1983). The fertility restorer gene Rfo was introgressed into oilseed rape from radish (Heyn 1976). As one or more gene controlling seed glucosinolates (GSL) content are linked to Rfo (Pellan-Delourme & Renard,1988; Renard et al. 1997; Delourme et al. 1998), additional research has been needed to improve the seed quality of fertiliser lines (low glucosinalotes content).

During the past 15 years, INRA in France has been working on this cytoplasmic male sterility system for hybrid seed production of winter-spring rape seed and canola. In its strategy to encourage the development of oilseed rape crops, its announced, together with SOFIPROTEOL, an optimised CMS OGU INRA restorer gene - the Rf-gene. The Rf Restorer technology is covered by a suite of patents and patent applications leading to the situation where SOFIPROTEOL has now assembled the full rights to negotiate and sub-license the use of the cloned Rf gene to develop Rf-gene modified lines restoring fertility of CMS OGU sterility, having low glucosinolates content and good transmission rate of Rf and without negative traits from radish introgression (low female fertility and vegetative vigour). The OGU-INRA CMS system is not the only hybrid technology that is being used by EU breeders. The German company NPZ developed a proprietary hybridisation technique in the 1990s. Today these two technologies are making that the EU seed business in oils seed rape is rapidly turning to hybrids. Over the next 10-15 years, hybrid varieties are likely to become the dominant force in oilseed rape in Europe. According to experts, German growers are today among the leading adopters of hybrid varieties in Europe, with 65 per cent of winter oilseed rape crops down to hybrids. This compares with 54 per cent in France and 37 per cent in the UK.

*Source: INRA*

Many more examples could be listed here. In each of the MS where plant breeding was supported by public funding, several success stories can be identified.

Privatisation took the form of a step by step process as summarised as follows.

***Step 1:** Delegation of M&S activities to a private seed company*

***Step 2:** Delegation of seed production activities to the same private commercial partner or to a third partner (farmers*

***Step 3:** Delegation of the variety testing and variety registration activities to the commercial partner*

***Step 4:** Delegation of the variety development phase to the commercial partner(s)*

***Step 5:** Delegation of all activities excepted germplasm improvement to the commercial partner(s)*

***Step 6:** Closure of the applied plant breeding activities*

The example of privatisation of the Plant Breeding Institute in the UK over the last 30 years illustrates perfectly this evolution.

**The Plant Breeding Institute (PBI) in the UK** was established in 1912 within the Cambridge University School of Agriculture. The Director, Sir Rowland Biffen is regarded as one of the first scientific plant breeders as he was among the first to demonstrate that Mendel's Laws could be applied to economically important crop characters. He discovered that wheat yellow rust resistance was simply inherited and used this knowledge to breed the rust resistant wheat variety "Little Joss".

The early work of the PBI was entirely devoted to the breeding of improved varieties of wheat, particularly with regard to better grain quality. Biffen insisted that breeding for improved crop quality must be based on research in crop genetics and physiology. In 1916, the variety "Yeoman" was released, which set a standard for yield and grain quality that would last many years; it remained on the National Institute of Agricultural Botany Recommended Varieties list until 1957.

In 1948, the PBI was established as an Agricultural Research Council institute, severing its formal link with Cambridge University. By this time the Institute included sections working on cereals, forage Crops, potatoes, sugar beet and cytogenetics.

In the mid to late 1970s PBI's science was characterised by studies on DNA organisation within wheat and its relatives. In 1978 ten new positions were created to exploit the emerging science of biotechnology and seven years later a new Department of Molecular Genetics was launched under R B Flavell.

In 1985 the Agricultural and Food Research Council's Forward Policy proposed that its research institutes should be re-organised into eight 'super' institutes. This was closely followed (1987) by the sale of the PBI breeding programmes and farm site to a private company (Unilever) under the government's privatisation policy. The non-privatised part of the PBI (the Cambridge Laboratory) was integrated into the Institute of Plant Science Research, which included the John Innes Institute

(Norwich) and the Nitrogen Fixation Laboratory (Sussex). In 1990 the majority of the PBI's scientific staff was relocated to newly built facilities at the John Innes Institute where they formed the 'Cambridge Laboratory'.
Over its 75 year history the PBI produced over 130 new varieties of wheat, barley, oats, triticale, potatoes, field beans, maize, oilseed rape, clover, sugar beet and grasses.

*Source: The John Innes Center*

When historical reviews of public plant breeding activities can be found in the literature, very few papers describe the evolution of the public funding in details. For example, it is very difficult to know how many breeders were in place at INRA in France or at PBI in the UK during the 1960s.

In MS where public breeding is still competitive on the market place, description of public efforts is also partial as public breeders do not want to disclose confidential information to their private competitors.

The Global Partnership Initiative for Plant Breeding Capacity Building (GIPB) has carried out surveys aiming at assessing public plant breeding capacity in 81 countries. In the EU 27 MS, assessments have been completed in only 5 MS (BG, CZ, SL, SK, and PT).

The following chapter presents the results of the analysis of the estimation of the actual and past public plant breeding efforts in the EU.

## 4.2 Mapping of the evolution and analysis of the capacities of the EU 27 MS public plant breeding sector.

The mapping of the evolution of the public breeding sector is based on the results of two complementary analyses as follows:

- Analysis of public plant breeding capacities (input and output sector parameters) based on the results of the survey questionnaire completed during the research phase ;
- Analysis of the evolution of the number of public variety maintainers listed in the agricultural and vegetables Common Catalogues of the European Commission[30].

### 4.2.1 Evolution of the public plant breeding capacities in the EU 27 MS

As presented above, the privatisation of the seed industry over the last 60 years has led to the significant reduction of public expenditures dedicated to the development and the marketing of new cultivars by the public sector. When some statistics exist in the USA to illustrate this shift of responsibilities and activities[31], too few data have been collated in the EU to understand this evolution.

One of the main objectives of this study is nevertheless trying to illustrate this evolution with quantitative data. Therefore a survey of the past and current applied public plant breeding efforts in releasing new varieties and cultivars in the EU 27 MS has been completed during the course of this study. This survey aimed to list most of the relevant public institutes and universities involved in breeding new varieties for their release on the market place and to estimate past and current resources and capacities of these institutes and universities still involved in applied plant breeding.

Only public breeders that are currently breeding new cultivars have been invited to fill the questionnaire. The segmentation between public and private breeding has created some issues when discussing with some organisations. Under this study, public breeding has to be understood as an activity performed by a legal entity, fully own by public legal entities, with no private funding investment in the applied plant breeding activities. Financing from the private sector occurs in the public/private partnerships and when a public entity is working

[30] **http://ec.europa.eu/food/plant/plant_propagation_material/plant_variety_catalogues_databases/index_en.htm**

[31] Frey K.J. 1996. National plant breeding study-I. Human and financial resources devoted to plant breeding research and development in the United States in 1994.

under a full cost recovery system. In this private funding occurs on a case by case basis only.

Only the public institutes that are still currently breeding new varieties have answered to the questionnaire and therefore historical data only address evolution for institutes that are still involved in breeding. Data from institutes or breeding programmes that stopped their activities since 2000 are not available, because no answers to the survey could be obtained. This remark applies for all cases where historical data (data series) are presented.

The comparisons that are presented in this analysis consider a 10 years period which is certainly not sufficient enough for a significant estimation of the evolution of the public plant breeding capacities but the research team considered that longer data series would have led to important data gaps. Then the compromise was to select a 10 years period.

Data from institutes or breeding programmes that have been stopped since 2000 are not included as these institutes have not answered to the survey questionnaire. Data are not available. This remark applies for all cases where historical data (data series) are presented. Efforts and capacities of public plant breeding efforts have been significantly reduced over the last 30 years and a comparison between 2000 and 2010 may not be seen a large enough to assess the evolution. A large number of privatisations did happen before 2000. The major examples of privatisation of applied public plant breeding efforts that has been observed since 200 are the one of Finland and Hungary. In Finland breeding of agricultural crops is done by Boreal (Jokioinen) which has the Finnish state as its majority owner[32]. The breeding programme is diversified and includes wheat, rye, barley, oats, spring turnip rape, forage grasses and clover, peas, field beans and potatoes, aimed at the development of varieties for the specific Finnish conditions. These different breeding programmes were located in several separate public entities in the past and have been grouped in a single one. Within Boreal only some activities (mainly breeding of minor crops and pre-breeding activities) are receiving public funding but in no cases, breeding is fully supported by public funding. Pre-breeding efforts are carried out in collaboration with the MTT, the Finnish institute for applied research for agriculture and food. The breeding of fruits (apple) and berries is done at MTTT Piikkio, close to Turkku, and is fully based on public breeding. Therefore only data for this latest programme are included in the data set of the study.

The second main example of "privatisation" is the case of the Szeged institute. Szeged is a very well-known institute in Hungary which a long history in the cereal breeding. Together with Novi-Sad in Serbia and the Fundulea in Romania, it is considered as one of the main public institute in the west-south of the EU. It was functioning as a state-owned institution since its foundation to 2008, belonging under the administration of the Ministry of Agriculture. It was taken over by the National State Property Agency Ltd since 1st January 2009, which manages state property and keeps the course of innovation in its entity and integrity. The company contributes to the competitiveness of agriculture with 183 registered plant varieties and hybrids of 23 plant species, the total growing area of which covers domestically and abroad ca. one million hectares annually[33].

Similarly we can mention the case of Agri-Obtention in France. However, that structure has been created before 2000 and delegation of plant breeding efforts to that private company based on majority of public ownership did start in the 1980-1990s and continued during the 2000s (e.g. winter oil seed rape).

Another question that arose during the study is to decide which activity has to be considered as an activity that leads to the release of new cultivars and especially in the field of molecular breeding. Public breeders have been invited to provide information for their molecular breeding activities in support to germplasm characterisation and to variety development. All other molecular breeding activities related to the pre-breeding activities are not included in the scope of this study.

## Representativeness of the completed answers to the survey questionnaire

The completeness of the responses is an important demonstration of the readiness and capabilities of the public

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[32] As private organisations own minority shares of the company, Boreal has not been invited to fill the survey questionnaire. Same applies to Agri-obtentions in France.

[33] Szeged annual report 2011.

sector to fulfil (or not) the objectives of the EU 2020 Strategy. Public plant breeders were invited to contribute to the survey during the 2012 summer period. The research team considers that the response rate is satisfactory and representative of the current public efforts for a level of 80-85% of the total EU seed market value[34]. A limitation to this analysis is the lack for completeness for Poland (even if an answer from the well-known IHAR has been received).

Information regarding the public plant breeding efforts situation in Bulgaria and Serbia are based on secondary data from international reports from the FAO in the context of the Global Partnership Initiative for Plant Breeding Capacity Building (Information available at: **www.km.fao.org/gipb/**). These two reports have been published in 2006 and data included corresponds to the situation in 2004-2005. For these two countries, when data series are presented, the year 2000 corresponds to the situation in 1990; and when data refers to the most recent year, data dates back to 2004-2005.

## Benchmark indicators

Serbia has been included in the study because it is a candidate for EU membership, it has a long history of public plant breeding and it is still heavily committed to the development, multiplication and marketing of new cultivars in the Balkan countries and in other markets too. Data from Serbia are used as a benchmark to measure the importance of the EU public efforts.

As a background indicator, the private plant breeding efforts should be reminded. The European Seed Association (ESA) estimates that the EU commercial seed market value has reached approximately between 7.0 and 7.5 billion Euros and represents more than 20% of the total worldwide market for commercial seed as the global certified seed market is estimated to have a turnover of around 26-29 billion Euros annually.

The seed industry has an annual R&D spending of about 12 to 15% of the total turnover (ESA, 2012), which means that total R&D budget (all activities included: genomics, pre-breeding, breeding) in the private EU R&D sector is estimated at around 800 million to 1 billion Euros annually.

In the EU 15 MS the number of personnel involved in R&D (plant breeding) in private companies is about 5,000 staff working in around 500 major research stations.

Two major groups of breeders co-exist in the EU:

- The SMEs that are used to breed for their local/national markets. These SME enter into partnerships with foreign seed partners for the purpose of testing/positioning, and when relevant, for marketing their existing cultivars in other countries characterised by specific growing conditions (breed locally – test globally) ;
- Large companies whose breeding strategy is a European wide and /or a global approach (e.g. hybrid crops) that consists in breeding for a given area of adaptation (breed globally-test locally).

## The list of public institutes and universities involved in the breeding of new cultivars

The list of relevant institutes/universities that have been identified[35] during the survey is presented in Annex 6.

Public breeding efforts are based on universities, agronomic institutes in which breeding is one of the activities or dedicated breeding institutes. The number of institutes per MS is not a relevant criterion to be considered in this study as the public breeding structure is largely dependent on how agricultural research is organised as a whole in a given country.

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[34] Estimation done by the research team based on its understanding of the sector and on the basis of the discussions with national experts and national competent authorities that took place during the course of the study. More information in Annex 3.

[35] See methodology of identification in Annex.

Public breeding efforts are based on universities, agronomic institutes in which breeding is one of the activities or on dedicated breeding institutes. The number of institutes per MS is not a relevant criterion to be considered in this study as the public breeding structure is largely dependent on how agricultural research is organised as a whole.

In Eastern countries, public plant breeding is coordinated via a national structure that includes satellite breeding stations distributed all over the country in order to test varieties locally (a testing network based on several locations).

In Estonia, the *Jovega Plant breeding institute* is an autonomous state research and development institute under the jurisdiction of the Ministry of Agriculture Estonia. The main activities of the institute include: variety breeding, applied research on agro-technical aspects, seed production, basic genetics research and heritability of valuable traits and maintenance of genetic resources.

In Lithuania, breeding in the Lithuanian Research Centre for Agriculture and Forestry started in Akademija near Dotnuva in 1922, when the famous Dr Rudzinskas, teacher and mentor to N.I. Vavilov, moved from St Petersburg to Dotnuva. The research centre is a state institute that is funded through the government (41% as core funding) and the Ministries of Education and Agriculture (17%)[36].

In the UK, plant breeding to produce finished varieties is very much a private sector activity and it has been so since the 1980s when the government decided that public money should no longer be used to support 'near market research', which included plant breeding. At that point the Plant Breeding Institute in Cambridge, where most public sector breeding had taken place, was sold. Today several independent institutes are performing some breeding activities. The James Hutton Institute breeds and commercialises potatoes and soft fruits. It also does barley breeding but not to the point of finished varieties. The Aberystwyth University (IBERS) breeds oats, which are commercialised by Senova, and grasses and clovers that are commercialised by Germinal Holdings. In Northern Ireland, the Agri-Food and Biosciences Institute (AFBI) breeds grass, which is commercialised by Barenbrug, and potatoes.

In France and Italy, the structure based on a single institute is rather similar. In France, all public plant breeding work is done by INRA; in Italy by the Consiglio per la Ricerca e la Sperimentazione in Agricultura though by different groups, each involved in a specific crop or group of crops.

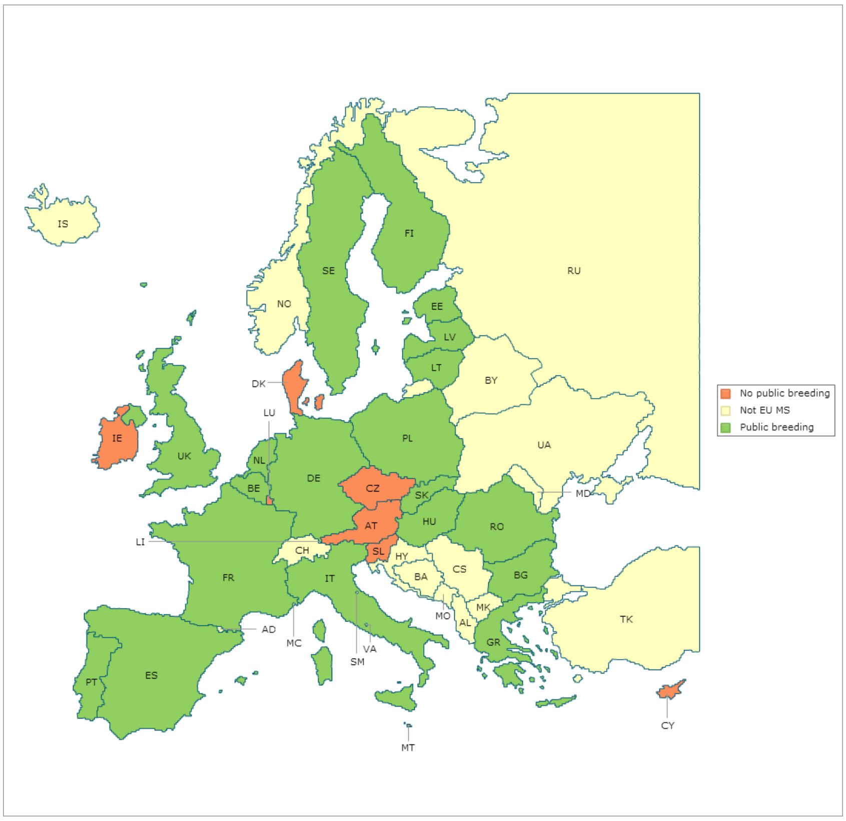
In Spain, several national and regional institutes are carrying out different programmes without any national coordination.

Eight MS have reported no public breeding activities in their country[37] (see following figure).

36 Von Bothmer R., Nilsson A. Collaboration between Baltic and Nordic Plant Breeding: a report from the investigation on measures to strengthen plant breeding set up by NMR. December 2010

37 Information mainly received from officials on charge of variety registration and/or variety protection and based on research team expertise.

**Figure 5 – MS in which public plant breeding occurs**




*Source: Survey questionnaire*

Five of these 8 MS (CY, IE, LU, MT, and SL) do not have a strong crop production history, therefore it is understood that research priorities do not include plant breeding. These markets are made of foreign varieties that are tested locally and released via the national or the European common catalogues. In the other three countries (AT, CZ and DK), a long history of plant breeding exists, and then the logic behind the lack of public plant breeding activities is less obvious.

## **Plant breeding efforts and resources (input)**

### *Plant breeding pattern by crop or group of crops*

The reduction of public plant breeding expenditures has led to the closure of a large number of breeding programmes in the EU 15 MS. In some NMS, the large majority of important national crops are still under consideration by public breeders (e.g. RO, BG). Although not visible in the following table, because the data set is incomplete, the same situation occurs in Poland. The situation in Estonia is particular as public breeding programmes are dedicated to more than ten different crops.

In Western countries, a rationalisation did occur. First it appears that crops well covered by the private sector were abandoned (e.g. hybrid crops, cereals). On the other hand, the example of legumes shows that public efforts are dedicated to crops no longer targeted by the private sector. Legumes were traditionally bred by cereal breeders. Reduction of acreage in these crops has had the consequence that private breeding legume programmes have been stopped.

In the other hand, the example of legumes shows that public efforts are focused on crops not considered any longer by the private sector. Legumes were traditionally bred by cereal breeders. Reduction of acreage for these crops (mainly due to their lack of yield stability) has had the consequence that private plant breeding legumes programmes have been significantly reduced and in most of cases stopped.

Secondly, rationalisation did also take the form of a prioritisation of crops based on the costs of the breeding programs. For example, sugar beet breeding programs are expensive especially in its variety testing phase, therefore public plant breeders have had to focus on species for which breeding costs are less expensive. Applied plant breeding is considered as "number game" meaning that it is recognised that more budget you have, more breeding material you can test, and then more chances to release need varieties you have. When your budget is limited, the number of varieties you can test is rather limited and then your chances to release competitive commercial varieties limited. This characteristic has led to strategies of concentrating breeding efforts on a small number of specie is instead ok keeping a large number of small breeding programmes. In that context the situation in Estonia is rather unique as public breeding programmes are dedicated to more than ten different crops.

When it relates to cereal crops, table 5 shows that public plant breeding efforts are not only focused on the main crop species which is winter wheat, but that other cereals such as triticale and oat are also considered. This can be explained that the breeding schemes are rather similar for the majority of cereal crops and therefore several species can be considered in the same breeding programme by the same breeder and the same breeding team. This is not the same for e.g. oilseed crops where different breeding programmes and different teams are required.

Winter oilseed rape is not any longer under significant consideration of public breeders. For a long time, oilseed rape has been bred by public breeders in the Western Europe as the main markets are in the UK, FR and DE. Poland (via the IHAR institute) is still active in the development of new cultivars for the Eastern European countries. When oilseed rape breeding in Western Europe is concentrated on winter oilseed rape, Poland is breeding winter and spring OSR.

Wine has a rather specific profile as most of the plant breeding efforts are concentrated in public institutes of two major countries (i.e. FR and DE). Slovakia is reporting testing of wine varieties but no variety development.

The following table shows that few vegetables, industrial and non-food and non-feed crops are bred by public institutes.

A majority of MS that have answered to the survey questionnaire is reporting a breeding activity in legumes (10 MS out of 18). Plant breeding of legumes species has been largely abandoned by the private sector as acreages have been significantly reduced during the last 20 years in the EU. The main reason of this decline in the production of legumes crops is due to the lack of yield stability for the main one being field peas. When yield level can be good one year making the crop financially interesting for the farmer, it can be poor the following year. Crop proteins from legumes have been replaced by cheaper crop protein extracted from soybean meal coming mainly from South America.

Sugar beet is bred by a public organisation in RO only. Variety testing of this crop is highly expensive as sugar beet is a heavy crop and that significant investment in machinery is required to set-up a variety testing network in that crop. Additionally, market size for this crop has been reduced over the last 10 years and therefore public plant breeding efforts are now concentrated in private breeders hands.

Very few public plant breeding efforts in vegetable crops and for the non-food and non-feed needs have been reported by the respondents of the survey.

The situation in Slovakia is rather unique and has to be considered specifically as the respondents to the general survey have indicated that only variety testing occurs in Slovakia. One may consider that variety testing alone should not be considered as a breeding activity. However, as these testing activities take place before the release of the varieties and carry out in support to variety registration (pre-registration trials), they are included in the data set of the study.

**Table 8 – Crops and group of crops bred by the public sector in the EU 27 MS**

| Type | Group of crops | Crops | EU 27 MS (in which public breeding occurs) | | | | | | | | | | | | | | | | | Serbia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BE | BG | DE | EE | ES | FI | FR | HU | IT | LV | NL | PL | PT | RO | SE | SK | UK | |
| Food&Feed | Cereals | Winter wheat | | X | | X | | | X | | X | | | X | X | X | | X | | X |
| | | Maize (silage and grain) | X | X | | | X | | X | | | | | X | X | X | | X | | X |
| | | Triticale | | X | | X | | | | | X | X | | X | X | X | | X | | |
| | | Other cereals | | X | | X | X | | | | X | X | | X | | X | X | X | X | X |
| | Oilseeds | Sunflower | | X | | | X | | | | | | | | | X | | X | | X |
| | | Winter oil seed rape | | | | | | | | | | | | X | | X | | X | | |
| | | Soybean | | X | | X | | | | | | | | | | X | | X | | X |
| | | Other oilseeds | | X | | X | X | | | | | | X | | | X | | X | | X |
| | Fodder plants | All gramineae | X | X | | X | | | | | | X | | X | X | X | X | | | X |
| | | All legumes (focus on field pea) | X | X | | X | X | | X | | X | X | | X | X | X | | X | | X |
| | | Other fodder plants | | | | | | | | | | | | | X | | | | | X |
| | Vine | Vine | | X | X | | | | X | | | | | | | | | X | | X |
| | Fruit | Apple | | | X | | | X | X | | | X | X | X | | X | X | X | | X |
| | | Other fruits | | X | X | | X | | X | | | X | | X | X | X | X | X | X | X |
| | Potatoes | Potatoes | | | | X | | | | X | X | X | X | X | | X | X | X | X | |
| | Vegetables | All Brassiceae | | X | | X | | | | | | | | X | | X | | X | X | X |
| | | All lettuces | | | | | | | | | | | | | | X | | | | X |
| | | All tomatoes | | X | | X | | | X | | | | | X | | X | | X | | X |
| | | Other vegetables | | | | X | | | | | | | | X | | | | | | |
| | Industrial crops | Sugar beet | | | | | | | | | | | | | | X | | | | X |
| | | Hop | | | | | | | | | | | | | | | | | X | X |
| | | Cotton | X | X | | | | | | | | | | | | | | | | |
| | | Other industrial crops | X | X | | | | | | | | | X | | | X | | | | |
| Non-Food | Biofuel 1st generation | Maize | | | | | X | | | | | | | | | | | | | |
| | | Oilseed rape | | | | | | | | | | | | | | X | | | | |
| | Biofuel 2st generation | Miscanthus | | | | | | | X | | | | X | | | X | | | | |
| | | Jatropha | | | | | X | | | | | | | | | | | | | |
| | | Poplar | | | X | | | | | | | | | | | | | | | |
| | Biomaterial | Maize | | | | | | | | | | | | | | | | | | |
| | Others | All | | | | | | | | | | | X | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| | | *Total* | *5* | *15* | *4* | *11* | *8* | *1* | *8* | *1* | *5* | *7* | *7* | *13* | *7* | *20* | *5* | *15* | *5* | *17* |

*Source: Survey results. Polish data set is not complete. Serbia and Bulgaria: 2006 FAO reports*

*Plant breeding pattern by activity*

Conventional plant breeding is a process of several activities. As presented under chapter 2, it starts by germplasm collection and characterisation supported by molecular breeding techniques, followed by variety development, then variety testing and variety registration occur before parental and commercial seed are produced for marketing and sales.

The previous table lists crops species that are bred by public institutes in general terms, but do not present which activities within the breeding schemes are carried out. All steps from germplasm characterisation to variety registration are required for the large majority of crop species to bring a new cultivar to the market and sharing of responsibilities between the public and private sectors occurs in a large majority of MS. Each MS/crop combination has a specific plant breeding model to adapt to commercial realities. However history has determined that each country has a general profile on how it has organised its plant breeding activities in relation to the private sector. That profile is presented in the following table[38].

Slovakia has a unique profile because its public organisation tests new cultivars of 16 different crop or group of crops. All other activities are carried out by the private sector.

To the exception of SK all other MS are logically reporting plant breeding activities in germplasm characterisation and variety development as these activities are the two core activities of a breeding programme.

For other activities being upstream such as molecular breeding or downstream such as variety testing, seed multiplication and variety and sales; different profiles can be observed as follows.

HU is reporting only molecular breeding and germplasm characterisation activities and not any follow-up activities. This is explained by the fact that results of these efforts are devoted to feed the Szeged breeding programmes that until very recently were fully public research activities. As some level of privatisation did happen, Szeged activities are not integrated in the data set of the study.

Only EE, LV, RO and the UK (one crop) have reported carrying out commercial activities to sell varieties they breed. In all other countries, marketing and selling activities are delegated to commercial companies. In some situations, public authorities are shareholders of these companies (Boreal in FI, Agri-obtentions in FR, Szeged in HU) but in the majority of cases delegation of marketing and sales are contracted out with long term private partners.

In Hungary, the molecular breeding and germplasm characterisation activities that are reported in the study are being performed by the university in support to Szeged breeding activities. First breeding phases are initiated within the University of Agriculture before material is transferred to Szeged breeders.

In the case of delegation of variety testing to partners, public institutes remain the official maintainer of the variety and are in charge of the first stage of parental seed production (breeder seed).

Serbia is involved in all activities from molecular breeding to sale of its own varieties.

To the exception of SK and HU, public institutes from all other countries have reported to be involved in germplasm characterisation and varietal development. Part of the variety testing phase (not all) may be contracted out.

Molecular breeding techniques are used on a case by case basis in breeding programmes as new techniques and technologies become available in a routine mode. In several countries, respondents to the survey have indicated that they are not involved in molecular breeding. In most of cases, this is explained by the fact that molecular techniques are not yet available in a routine cost-effective mode for these crops.

Tendency is to concentrate on the two core activities of the breeding scheme being germplasm characterisation and variety development (i.e. nursery work) and delegate other activities to either other public organisation or to the private sector.

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[38] For sought of clarity, sharing of responsibilities between public and private sectors is presented per MS and not at MS/crop combination level.

**Table 9 – Public plant breeding activities: MS general profile**

| Activity | EU 27 MS (in which public breeding occurs) | | | | | | | | | | | | | | | | | Serbia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BE | BG | DE | EE | ES | FI | FR | HU | IT | LV | NL | PL | PT | RO | SE | SK | UK | |
| Molecular breeding (MolBreed) | X | | X | X | X | | X | X | X | X | X | X | | | X | | X | X |
| Germplasm caracterisation (GermCar) | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X |
| Variety development (VarDev) | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | | X | X |
| Variety testing (VarTest) | X | X | X | X | X | X | X | | X | X | X | X | X | X | X | X | X | X |
| Parental seed production (ParSeedProd) | X | | X | X | X | | X | | X | X | | X | X | X | X | | | X |
| Commercial seed production (ComSeedProd) | | | | X | X | | | | | X | | X | | X | | | | X |
| Marketing and sales (SeedMark) | | | | X | X | | | | | X | | X | | X | | | X | X |

*Source: Survey results. Polish data set is not complete. Serbia and Bulgaria: 2006 FAO reports*

Table 9 presents the global profile of activities run by the public sector. Not all activities presented in the table are carried out for all crops. Respondents to the general survey questionnaire were asked to provide dedicated information per crop or group of crops.

The analysis of these data shows different approaches within a given MS and even within a given institute. These differences demonstrate that for each crop or group of crops, a dedicated plant breeding scheme is designed. Molecular breeding techniques are applied when they can be applied in a routine mode at an affordable cost. In the large majority of cases public breeders are keeping the responsibility of the production of parental seed. In conclusions, sharing of responsibilities between the public sector and private sector is defined at the crop level.

*Public plant breeding pattern in terms of staff*

The estimate of staff involved in conventional breeding offers an overview of the public efforts to the creation and release of new varieties.

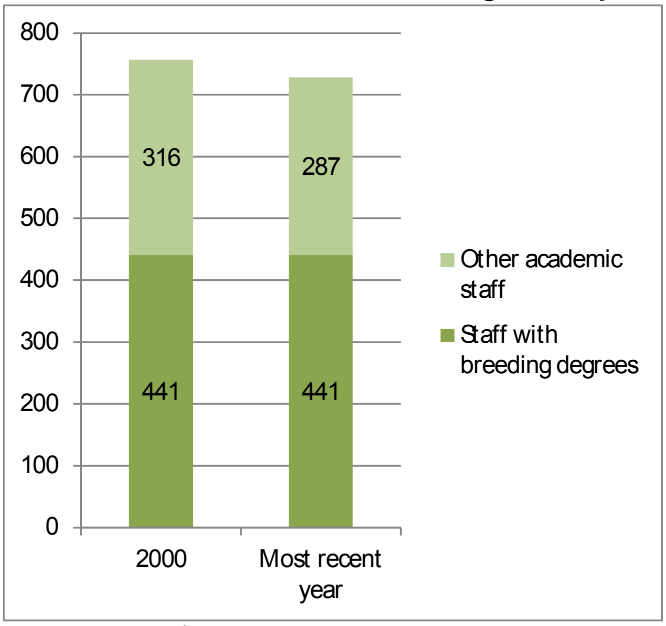
Common usage of the terms "plant breeding" and "plant breeder" often imply homogenous activities and a singular group of people with common expectations, goals, and tasks. However, to accommodate the multidisciplinary nature of plant breeding, three categories—cultivar breeding, germplasm enhancement, and breeding research (Frey, 1996)—with an additional one, biotechnology, added in 2001 (Traxler et al., 2005), were used to identify and quantify resources allocated to breeding activities in the United States. Similar categories that characterize allocation of efforts (i.e., germplasm improvement, line development, line evaluation, and biotechnology) are used by the FAO to assess plant breeding and biotechnology capacities in developing countries (Guimaraes et al., 2006).

Contributions of other academic staff and non-scientists to overall crop improvement should also be acknowledged. This is mainly the case for the majority of the field work which is being carrying out (i.e. sowing, manual crossing in nurseries, harvesting of testing plots, production of seed required for testing purposes, etc…). Therefore, the present study analyses staff resources in two complementary categories: first, staff with plant breeding degrees (mainly plant and molecular breeders) and secondly, staff with other academic degrees (assistants to breeders, technicians,…). Only full time equivalents have been inventoried and not part time workers.

Across all crop species covered by the study, the total number of full time staff involved in public plant breeding in the EU 27 MS is currently estimated at 728 Full Time Equivalent (FTE) of which 441 staff have breeding degrees. In 2000, the total staff was estimated at 757.

It can be observed that over the period 2000-2010, the number of staff has been rather flat (757 in 2000 and 728 in 2010). A staff reduction of about 7% is affecting the category with no breeding degrees (mainly assistant breeders and technicians) and not the breeders per se. Staff reduction would have been more pronounced if closures of public institutes (or privatisation) since 2000 would had been taken into consideration and for which no EU statistics exist.

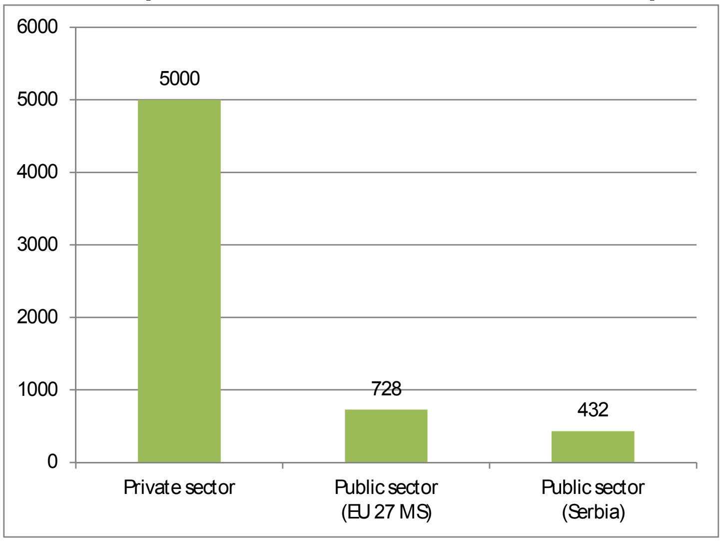
**Figure 6 - Staff evolution in conventional public plant breeding institutes in the EU 27 MS[39] (for institutes in which conventional breeding currently occurs)**




*Source: Survey results*

The FAO report for Serbia alone reports that 432 staff are dedicated to the development of new cultivars. This statistic of 728 FTEs must be compared with the 5,000 staff ESA reports for the private sector. Its current public breeding staff represents about 10 to 12 % of the total breeding staff in the EU 27 MS. **By extrapolating the survey results, the research team considers that public breeders represents about 15% of the total breeding community in the EU 27 MS.**

**Figure 7 - Staff comparison in the EU 27 MS vs. Serbia and the private sector**




*Source: Survey results*

[39] Serbia not included

The evolution per MS stands as follows.

**Table 10 – Staff evolution in public plant breeding in the EU 27 MS**

**2000**

| Activity | EU 27 MS (in which public breeding occurs) | | | | | | | | | | | | | | | | | | Serbia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BE | BG | DE | EE | ES | FI | FR | HU | IT | LV | NL | PL | PT | RO | SE | SK | UK | Total | |
| Staff with breeding degrees | 7.0 | 119.0 | 15.0 | 13.3 | 15.5 | 0.0 | 8.8 | 0.0 | 19.5 | 15.4 | 4.0 | 61.0 | 12.0 | 26.0 | 1.3 | 117.0 | 6.3 | **441.0** | 182.0 |
| Other academic staff | 2.0 | 118.0 | 14.0 | 4.0 | 18.0 | 2.0 | 41.9 | 10.0 | 13.0 | 16.0 | 6.0 | 36.0 | 16.0 | 8.0 | 3.3 | 0.0 | 7.7 | **315.8** | 326.0 |
| *Total* | *9.0* | *237.0* | *29.0* | *17.3* | *33.5* | *2.0* | *50.7* | *10.0* | *32.5* | *31.4* | *10.0* | *97.0* | *28.0* | *34.0* | *4.5* | *117.0* | *14.0* | ***756.8*** | *508.0* |

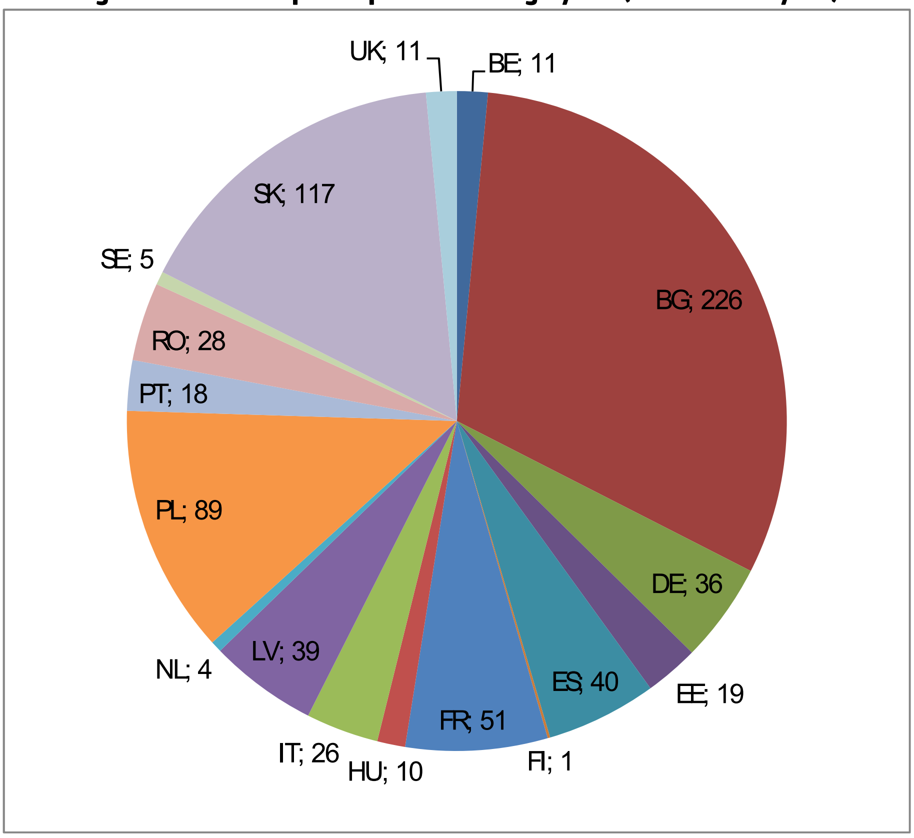
**Most recent year**

| Activity | EU 27 MS (in which public breeding occurs) | | | | | | | | | | | | | | | | | | Serbia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BE | BG | DE | EE | ES | FI | FR | HU | IT | LV | NL | PL | PT | RO | SE | SK | UK | Total | |
| Staff with breeding degrees | 9.0 | 117.0 | 19.5 | 13.3 | 18.5 | 0.0 | 8.8 | 0.0 | 19.0 | 19.6 | 2.0 | 62.0 | 9.0 | 19.0 | 1.3 | 117.0 | 6.3 | **441.2** | **146.0** |
| Other academic staff | 2.0 | 109.0 | 16.0 | 6.0 | 21.0 | 0.9 | 41.9 | 10.0 | 7.0 | 19.0 | 2.0 | 27.0 | 9.0 | 9.0 | 3.5 | 0.0 | 4.6 | **287.9** | **286.0** |
| *Total* | *11.0* | *226.0* | *35.5* | *19.3* | *39.5* | *0.9* | *50.7* | *10.0* | *26.0* | *38.6* | *4.0* | *89.0* | *18.0* | *28.0* | *4.8* | *117.0* | *10.9* | ***729.1*** | *432.0* |
| *Evolution since 2000* | *22.2* | *-4.6* | *22.4* | *11.6* | *17.9* | *-55.0* | *0.0* | *0.0* | *-20.0* | *22.9* | *-60.0* | *-8.2* | *-35.7* | *-17.6* | *5.6* | *0.0* | *-22.1* | | *-15.0* |

*Source: Survey results. In yellow: estimations (i.e. use of 2008 data) as 2000 data were not provided by respondents to the survey. In green: polish data that are incomplete. Serbia and Bulgaria: 2000 data refers to the situation in 1990 and most recent year data refers to the 2004-2005 data*

Bulgaria alone represents about 30% of the total number of staff. In comparison, the number of public staff in the major seed countries of the EU 15 MS is limited to a maximum of 51 in France, 40 in ES and less in DE and IT (36 and 26 respectively).

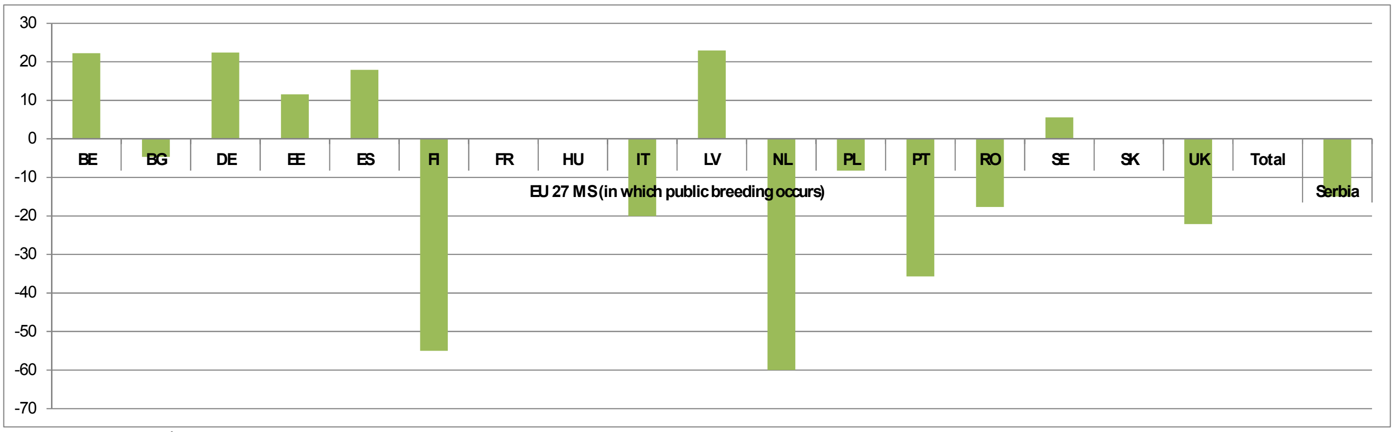
**Figure 8 – Staff in public plant breeding by MS (most recent year)**




*Source: Survey results*

The evolution during the last 10 years shows large differences across MS. In six countries out of 17, it a slight increase (less than 20%) of staff is observed; conversely, a significant decrease (up to 60%) is observed in FI, IT, NL, PT and the UK over the 2000-2010 period.

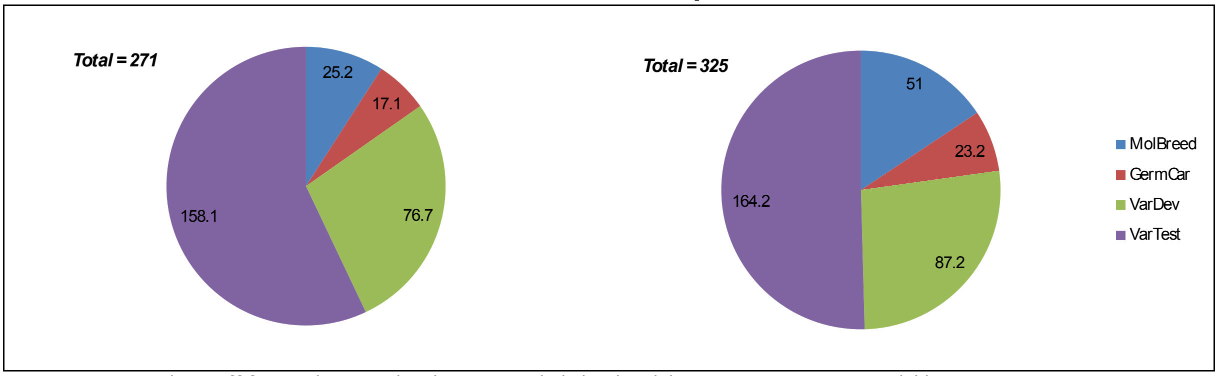
**Table 11 - Staff evolution in public plant breeding by MS (in %) (2000-2010)**




*Source: Survey results*

The staff repartition per breeding activity shows slight evolutions over the last ten years.

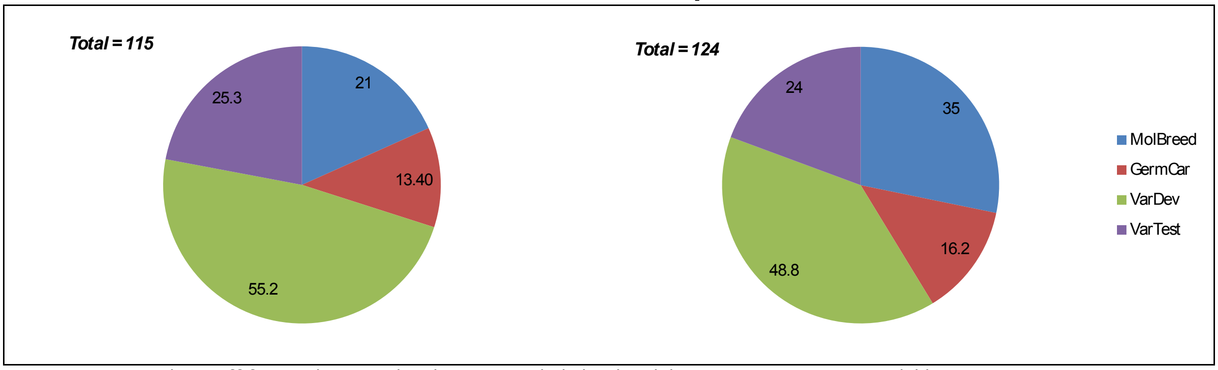
**Figure 9 - Evolution of the repartition of staff with breeding degrees per breeding activity (2000-most recent year)**




*Source: Survey results. Staff from Bulgaria and Serbia is not included as breakdown per activity is not available*

The majority of the staff is involved in variety testing which is known as being an activity which is requiring lot of resources for running the field trials. The number of staff is the two core activities of the conventional plant breeding (i.e. germplasm characterisation and variety development) is rather stable over time and together it represents about 20% of the total staff. When it relates to molecular breeding, it can be observed a significant increase in the number of staff over the last 10 years which is explained by the integration of novel molecular breeding techniques in breeding programmes.

**Figure 10 - Evolution of the repartition of other academic staff per breeding activity (2000-most recent year)**




*Source: Survey results. Staff from Bulgaria and Serbia is not included as breakdown per activity is not available*

The staff distribution for other academic staff is different as the majority of that staff is dedicated to variety development. Similarly to the staff with breeding degrees, the number of other academic staff dedicated to molecular breeding activities has increased significantly over the last ten years. The staff dedicated to the two other activities (i.e. germplasm characterisation and variety testing) remains stable over the last decade.

These raw data are interesting from a descriptive point of view, however they do not give any indication of the real efforts across crop species as breeding schemes are crop specific.

*Public plant breeding pattern in terms of financial resources*

Respondents to the survey have been invited to provide information related to their funding mechanisms and the availability of resources for conventional applied plant breeding activities. Less than 50% of the research institutes to the survey questionnaire have provided financial information in their response. When staff figures were provided, we have estimated the budget for staff and per MS. In these cases only staff budgets are presented and these estimations do not include budgets for investments, machinery and other costs.

Therefore, data that are presented hereafter have to be considered carefully as they present a rough estimation of budgets, including only staff costs, and in no case they have to be taken as precise figures. For this reason we present only a general overview of the financial data. Presenting a breakdown of these data per crop or per breeding activity may lead to misunderstandings. The research team is of the opinion that these budget figures are underestimated at a level of 30-50% for MS and institutes for which estimation is provided (no data provided for BE, FR, and PT ; partial data for DE).

In total, a total current applied plant breeding expenditure of 15.7 million Euros has been estimated while it was estimated of 15.4 million Euros in 2000.

In Serbia alone, the annual budget for public breeding is estimated at 20 million Euros in 2004-2005.

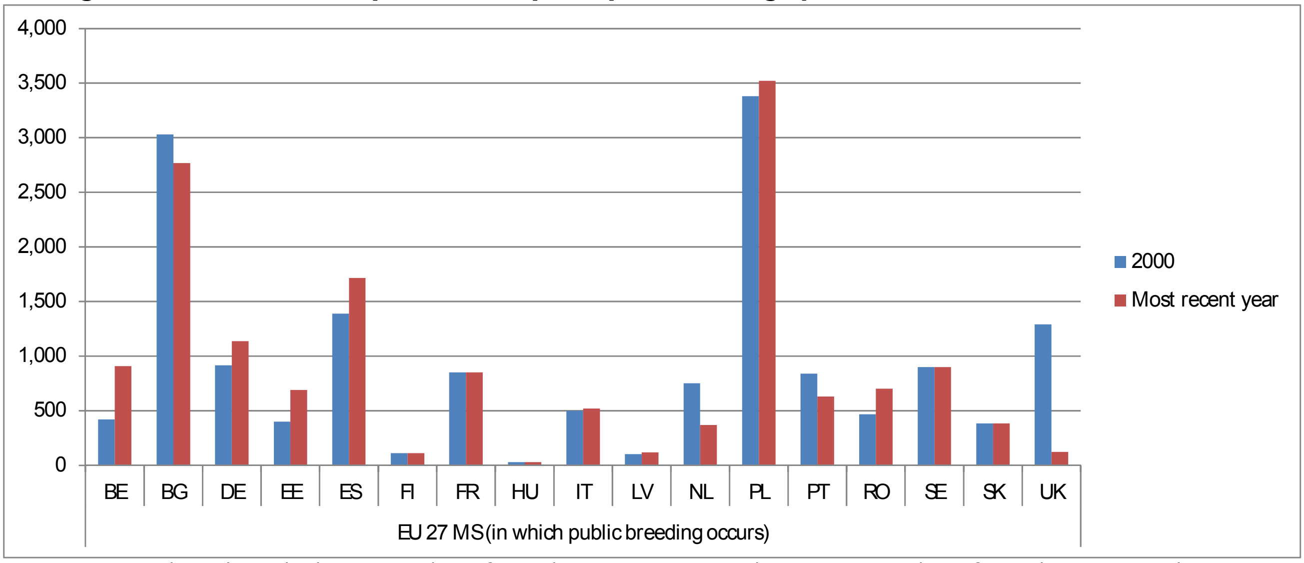
Representatives of the private sector that have been met during the study consider that the seed industry is investing 12-15% of his annual turnover in R&D (genomics and pre-breeding included). On the basis of an annual turn-over of 7 billion Euros, R&D expenditures of the private sector are estimated at 800-900 million Euros per year.

**Table 12 - Evolution of expenditures in public plant breeding by MS (in K Euros) (2000-2010)**

| Activity | EU 27 MS (in which public breeding occurs) | | | | | | | | | | | | | | | | | | Serbia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BE | BG | DE | EE | ES | FI | FR | HU | IT | LV | NL | PL | PT | RO | SE | SK | UK | Total | |
| 2000 | 420 | 3,032 | 917 | 399 | 1,389 | 111 | 850 | 30 | 500 | 102 | 750 | 3,380 | 840 | 467 | 900 | 384 | 1,291 | **15,762** | 16,400 |
| Most recent year | 910 | 2,769 | 1,136 | 691 | 1,717 | 111 | 850 | 30 | 520 | 118 | 370 | 3,521 | 630 | 702 | 900 | 384 | 123 | **15,482** | 20,400 |

*Source: Survey results. In yellow: estimates (i.e. use of 2008 data) as 2000 data were not provided by respondents to the survey. In green: polish data that are incomplete. Serbia and Bulgaria: 2000 data refers to the situation in 1990 and most recent year data refers to the 2004-2005 data*

**Figure 11 – Evolution of expenditures in public plant breeding by MS (in K Euros) (2000-2010)**




*Source: Survey results. Serbia and Bulgaria: 2000 data refers to the situation in 1990 and most recent year data refers to the 2004-2005 data*

Bulgaria and Poland are the two MS in which the major investments occur (about 3 million Euros each). Total investments in these two MS represent about 45% of the total EU 27 MS investments.

For most MS, the annual expenditures in conventional breeding activities have increased or remained stable (for institutes and universities that continue to be involved in conventional breeding). A significant decrease is observed in only four MS: BG, NL, PT, and the UK. For all other MS an increase which is often rather marginal is observed. This situation can be explained by the fact that optimisation and rationalisation did occur in a large majority of MS. When some breeding programmes have been abandoned, others have partially benefited from additional resources.

Budget reductions are often explained by a political wish to not support any longer any applied agricultural research activities. In that global context, plant breeding activities did follow the same general trend. When capacities, resources, and investments were available; they have been partially transferred to the remaining public plant breeding activities. Public plant breeding activities have been kept to complete gaps and activities not fully covered by the private sector. For example, the French approach by INRA is clearly to perform applied plant breeding on activities not covered by the private sector. When overlaps are observed, the public activities are reduced or even fully stopped.

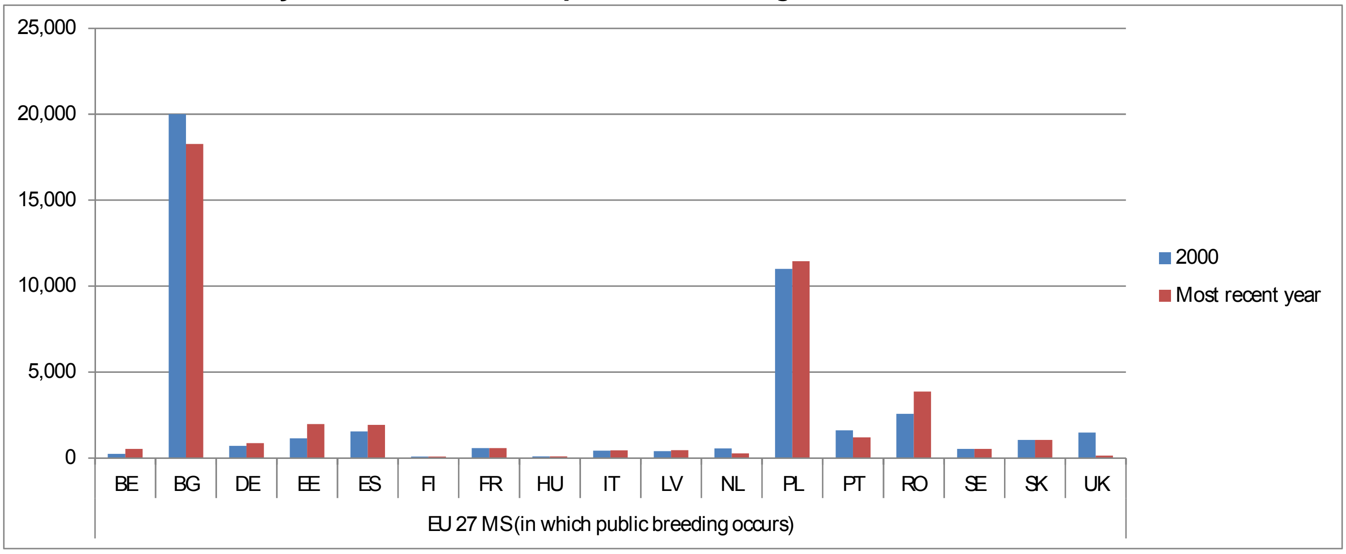
A large majority of the breeding costs are labour and staff costs. As labour cost per hour in Euros are largely variable across MS (e.g. 39 Euros in Belgium, 3.5 Euros in Bulgaria); we are presenting in the following table a comparison of the public expenditure adjusted at the EU 27 MS average labour cost per hour of 23.1 Euros. This adjustment allows a more precise comparison between MS.

**Table 13 – Evolution of expenditures in public plant breeding by MS (in K Euros) (Adjusted labour cost hourly rate to EU average) (2000-2010)**

| Activity | EU 27 MS (in which public breeding occurs) | | | | | | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BE | BG | DE | EE | ES | FI | FR | HU | IT | LV | NL | PL | PT | RO | SE | SK | UK | |
| *2000* | *420* | *3,032* | *917* | *399* | *1,389* | *111* | *850* | *30* | *500* | *102* | *750* | *3,380* | *840* | *467* | *900* | *384* | *1,291* | ***15,762*** |
| *Most recent year* | *910* | *2,769* | *1,136* | *691* | *1,717* | *111* | *850* | *30* | *520* | *118* | *370* | *3,521* | *630* | *702* | *900* | *384* | *123* | ***15,482*** |
| *Labour Cost/hour* | *39.3* | *3.5* | *30.1* | *8.1* | *20.6* | *29.7* | *34.2* | *7.6* | *26.8* | *5.9* | *31.1* | *7.1* | *12.1* | *4.2* | *39.1* | *8.4* | *20.1* | |
| *Average EU 27 MS labour cost/hour* | *23.1* | | | | | | | | | | | | | | | | | |
| 2000 (adjusted) | 247 | 20,011 | 704 | 1,138 | 1,558 | 86 | 574 | 91 | 431 | 399 | 557 | 10,997 | 1,604 | 2,569 | 532 | 1,056 | 1,484 | **44,037** |
| Most recent year data (adjusted) | 535 | 18,275 | 872 | 1,971 | 1,925 | 86 | 574 | 91 | 448 | 462 | 275 | 11,456 | 1,203 | 3,861 | 532 | 1,056 | 141 | **43,763** |

*Source: Survey results. In yellow: estimations (i.e. 2008 data) as 2000 data were not provided by respondents to the survey. In green: polish data that are incomplete. Serbia and Bulgaria: 2000 data refers to the situation in 1990 and most recent year data refers to the 2004-2005 data*

**Figure 12 - Evolution of expenditures in public plant breeding by MS (in K Euros) (Adjusted labour cost hourly rate to EU average) (2000-2010)**




*Source: Survey results. Serbia and Bulgaria: 2000 data refers to the situation in 1990 and most recent year data refers to the 2004-2005 data*

This adjustment further highlights the importance of public plant activities in EU Eastern countries and more particularly in BG, PL and RO. Adjusted budgets for these 3 MS represent more than 32.5 million Euros out of a total EU adjusted budget estimated at 44 million Euros. The highest adjusted budget in the EU 15 MS is observed in Spain with an annual budget of about 2 million Euros which represents only 50% of the budget in RO and a budget slightly lower than EE alone (1.971 million Euros in EE and 1.925 in ES).

The total of the adjusted budgets of the main western European agricultural countries (i.e. FR, DE, NL and IT) is estimated at only 2.169 million Euros (6-7% of the total adjusted EU expenditures).

Financial resources and available budgets are optimised by either contracting out (selling) activities if there is exceeding capacity or contracting in if missing expertise must be bought.

**Table 14 - Contracting in and contracting out activities by public breeders in the EU 27 MS in 2010 (in K euros)**

| | MolBreed | GermCar | VarDev | VarTest | Total |
|---|---|---|---|---|---|
| **Contrating IN** | **344** | **108** | **207** | **150** | **809** |
| *Of which from public organisations (%)* | *80* | *10* | *25* | *10* | |
| *Of which from private organisations (%)* | *20* | *90* | *75* | *90* | |
| **Contracting OUT** | **2** | **46** | **180** | **828** | **1,056** |
| *Of which to public organisations (%)* | *0* | *3* | *0* | *2* | |
| *Of which to private organisations (%)* | *100* | *97* | *100* | *98* | |
| *Balance* | *-342* | *-62* | *-27* | *678* | *247* |

*Source: Survey results*

Public breeders report that they are contracting in activities at the level of 800 K Euros the majority of which is for molecular breeding support. Most of this technical support comes from other public entities. Financial income related to the three other activities, namely germplasm characterisation, variety development and variety testing, comes from the private sector and from commercial partners that are in charge of marketing varieties developed by the public breeders.

Contracting out activities is estimated at about 1 million Euros per year in the EU 27 MS, out of which 800 K euros were reported by the Belgian public breeding sector. Public support mainly goes to the private sector. When excluding the Belgian figure, it can be concluded that public breeders are not contracting out activities to other public entities nor to the private sector, i.e. their capacity fit their own needs.

Each breeding programme has a specific approach regarding the contacting in and contracting out of activities from which no concrete conclusions can be drawn. Answers from the respondents of the survey are as follows.

**Table 15 - Contracting in activities by public breeders per MS in 2010 (in K euros)**

| MS | Crop | Breeding activities: contracting IN activities (in K Euros per year) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total (in Keuros) | | | | Of which from private organisations (in % of total) | | | | Of which from other public organisations (in % of total) | | | |
| | | Mol Breed | GermCar | VarDev | VarTest | Mol Breed | GermCar | VarDev | VarTest | Mol Breed | GermCar | VarDev | VarTest |
| EE | Potatoes | | 34.0 | | | | 100.0 | | | | | | |
| ES | all | | 30.0 | | | | 80.0 | | | | 20.0 | | |
| ES | All | 110.0 | | 21.7 | | | | 100.0 | | | | 100.0 | |
| FR | ALL | | | 60.0 | 30.0 | | | 100.0 | 100.0 | | | | |
| IT | ALL | | | 40.0 | | | | 25.0 | | | | 75.0 | |
| LV | ALL | 156.0 | 14.0 | | | | | | | 100.0 | 100.0 | | |
| NL | Hop | | 14.2 | 45.3 | 14.0 | | 100.0 | 91.0 | 60.0 | | 0.0 | 9.0 | 40.0 |
| RO | ALL | | | | 106.0 | | | | 100.0 | | | | |
| SE | Gramineae | | | 40.0 | | | | 50.0 | | | | 50.0 | |
| SK | Potatoes | 60.0 | | | | 40.0 | | | | 60.0 | | | |
| UK | ALL | 18.0 | 16.0 | | | 100.0 | 100.0 | | | | | | |

*Source: Survey results*

**Table 16 - Contracting in activities by public breeders per MS in 2010 (in K euros)**

| MS | Crop | Breeding activities: contracting OUT activities (in K Euros per year) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total (in Keuros) | | | | Of which to private organisations (in % of total) | | | | Of which from other public organisations (in % of total) | | | |
| | | Mol Breed | GermCar | VarDev | VarTest | Mol Breed | GermCar | VarDev | VarTest | Mol Breed | GermCar | VarDev | VarTest |
| **BE** | ALL | | 20.0 | 100.0 | 800.0 | 100.0 | 100.0 | | | | | | 100.0 |
| **DE** | Poplar | 2.0 | | | | | 100.0 | | | | | | |
| **ES** | All | | 20.0 | 26.6 | | 50.0 | | 100.0 | | 50.0 | | | |
| **HU** | Potatoes | | 6.0 | | | | | | | 100.0 | | | |
| **LV** | ALL | | | | 28.0 | | | | 100.0 | | | | |
| **LV** | All | | | 2.0 | | | | 100.0 | | | | | |
| **UK** | Hop | | | 51.4 | | | 83.0 | | | | 17.0 | | |

*Source: Survey results*

*<u>Expertise, equipment and facilities to use biotechnology techniques, especially new plant breeding techniques</u>*

The large majority of respondents to the general survey have provided qualitative information related to their equipment and facilities related to the use of new and modern breeding technologies.

Globally, it seems that public research institutes and universities are not suffering from a lack of resources as expertise, equipment and facilities are available for the use of biotechnology in the breeding programmes, but in several cases (e.g. CRA in IT, SLU in SE) funding is lacking to fully use these existing capacities.

Standard equipment for plant genetic and molecular analyses such as DNA and RNA extraction as well as PCR equipment tools to support marker-assisted selection and for genetical characterisation of germplasm are largely available. Additional standard lab facilities seem to be available when required to optimise and speed-up breeding processes. Molecular lab facilities include greenhouses in which cross-breeding, tissue culture, double-haploid production and embryo rescue techniques can be deployed.

Several respondents have indicated a loss of expertise and equipment in the field of GM technologies due to the lack of acceptance of GM crops in the EU. For example, the UNIBO university in Italy is reporting that in the past, transgenic maize using biolistic system were produced but that the activity stopped about five years ago. However the equipment is still available bur not used any longer.

In case, technology and equipment is not available, research institutes have capacities in being able to utilise the expertise resident at other public centres involved in more fundamental research units.

In a limited number of cases (e.g. PRI in the NL) cisgenesis and transgenesis GM technologies are being used. For other new techniques it seems that public researchers are currently investigating other novel breeding techniques but none are used for commercial applications yet.

## Plant breeding results (outputs)

Via the general survey, academia and public plant breeders in the EU 27 MS were invited to provide information related to the breeding results (number of released varieties and traits concerned) and financial income from plant breeding (revenues and public funding).

*Number of released varieties & traits concerned*[40]

The first criterion considered to assess public plant breeding outputs is the number of varieties released by public breeders over the 2000-2005 and 2005-2010 periods. When it is recognised that a period of 10 years is not sufficiently significant, the research team considered that it was not suitable to ask for older statistics often not available any longer.

In order to correctly analyse figures presented by the respondents to the survey, it should be highlighted that plant breeders are used to release a large number of varieties that marketing and sales units will bring to the market only a few of them. Each of the EU Common Catalogues contains more than 20,000 varieties. Additionally, the number of Community Plant Variety Rights (CPVR) applications and CPVR awarded has steadily increased since the regime came into force in 1995.

In 2009, 2,866 titles were granted by the Community Plant Variety Office (CPVO) in Angers and the number of applications reached the number of 2,956 in the same year. To these figures, it should be added the protection titles granted by national authorities and for which there is no statistics available to date at the Community level.

In comparison to these figures, **the number of varieties released by the public sector is negligible.**

**Table 17 - Evolution of the number of varieties released by the EU 27 MS public breeders (2000-2010)**

| Period | EU 27 MS (in which public breeding occurs) | | | | | | | | | | | | | | | | | Total | Serbia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BE | BG | DE | EE | ES | FI | FR | HU | IT | LV | NL | PL | PT | RO | SE | SK | UK | | |
| 2000-2005 | 34 | 90 | 6 | 12 | 46 | 11 | | | 20 | 42 | 9 | 173 | 9 | 80 | 14 | n.a. | 11 | 557 | 247 |
| 2005-2010 | 24 | 95 | 11 | 10 | 27 | 10 | | | 38 | 22 | 15 | 199 | 11 | 54 | 14 | n.a. | 20 | 550 | 318 |
| ***Evolution*** | =↘ | = | = | =↘ | ↘↘ | ↘↘ | = | | ↗↗ | = | ↗ | =↗ | =↘ | =↘ | = | | = | | |

*Source: survey results. Serbia and Bulgaria: 2000 data refers to the situation in 1990 and most recent year data refers to the 2004-2005 data*

Public breeders that have responded to the general survey questionnaire report the registration of 550 varieties over a five years period (2005-2010) which is a slight decrease of about 2% over the 2000-2005 period. In comparison, Serbia alone has registered about 318 over the same period (+ 23% over the 2000-2005 period).

The main reason explaining the reduction of number of released varieties is the decline of resources. Plant breeding is characterised by a strong correlation between available resources and number of released varieties. Plant breeding is "still" considered as a "number game"[41]: the number of released varieties is highly correlated with the number of varieties that have been tested and the number of crosses that have been initiated in nurseries. With a larger budget, the breeder can increase the number of crosses and varieties under testing, so the chances

[40] Additional information is provided in annex

[41] Common knowledge

to register more varieties increase. Therefore with a large tendency to reduce budgets and public capacities, the number of varieties released by public breeding tends to decrease proportionally to the available budgets.

Only IT, the NL and Poland (partial data) are reporting an increase in the number of released varieties. In all these countries, new breeding programmes have been initiated during the last 20 years and delivery of new varieties took several years. In 2000, the programme was still at an early stage and variety not ready yet. After more than 10 years of efforts, breeding schemes reached maturity and results of the programme became visible via the release of several new cultivars.

**None of the varieties that have been released during the 2000-2010 period are transgenic varieties. The main traits that have been registered by public breeders are yield for agricultural crops linked to resistances to the major plant diseases that are not controlled by plant protection products. Quality traits such as protein content and oil content are also concerned but to a lesser degree.**

It should be highlighted that breeding cycles, which are crop specific, are rather long. In general it is estimated that breeding a new variety takes a minimum of 8 to 10 years from the original cross to the commercial release of the variety. **Therefore figures of released varieties and traits concerned that have been reported by the public breeders concern decisions taken by the breeders in the early to the mid-1990s. At that time breeding needs were to improve quality content of varieties and other traits/criteria such as those related to respecting environment. The development of specific cultivars for industrial use and biofuel production were not yet in the breeders'agenda**.

*Market description*

A large majority of varieties that are bred by public breeders are marketed by private commercial partners, which are trying to optimise market opportunities. This expansion largely depends on the nature of the seed. In cereal crops, more than 200 kg of seed per hectare is required, meaning that moving seed over different markets is rather expensive as it requires important logistics ; therefore extending markets is not profitable as the return of cereal crops (other than maize) is low. On the contrary, high value hybrid crops and small seed (e.g. vegetable species and ornamental seed) can easily be transported from one area to another, which means that reaching several markets becomes feasible.

**Table 18 - Market penetration for varieties released by public breeders by MS (2010)**

| Market | EU 27 MS (in which public breeding occurs) | | | | | | | | | | | | | | | | | Serbia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BE | BG | DE | EE | ES | FI | FR | HU | IT | LV | NL | PL | PT | RO | SE | SK | UK | |
| Domestic market | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | X |
| EU 27 MS | X | X | X | X | X | | X | X | X | X | X | X | X | X | X | | X | X |
| Other EU | X | | X | X | X | | X | | X | | X | X | | X | X | | X | X |
| Outside EU | NZ | | | Russia | X | | | | | | South America | Canada | | Argentina | | | USA | > 50 countries |
| | USA | | | | | | | | | | | Chile | | China | | | Australia | |
| | | | | | | | | | | | | Ukraine | | Moldovia | | | Canada | |
| | | | | | | | | | | | | USA | | Turkey | | | Norway | |
| | | | | | | | | | | | | | | and | | | Serbia | |
| | | | | | | | | | | | | | | > 20 countries | | | South Africa | |

*Source: survey results. Serbia: 2006 data*

Most of public institutes and universities are considering their domestic market as the priority but do not underestimate the EU market as the EU legislation on marketing of seed varieties has established an internal market based on the EU Common Catalogues. For the large majority of agricultural crops and vegetable crops, as soon as a variety is registered in a national catalogue, it is included in the EU CC that allows marketing in any of the EU MS. Therefore, marketing of cultivars via commercial partners in non-domestic MS does not involve large costs as access to the market is obtained via the EU CC and as seed multiplication can be delegated to the commercial marketing and sales partner(s). Public breeders largely use these opportunity to wider their market.

Market development also depends largely on historical relationship between countries and on the crops. Only, RO and SE seem to have developed commercial activities at large in neighbour countries but also in other potential markets. These two countries have reported to sell their varieties in more than 20 and 50 countries for RO and Serbia respectively in addition to their domestic and the EU markets. In these countries, varieties have to be registered before any marketing can take place. Therefore these additional markets have not to be seen as opportunities but are based on true market development objectives.

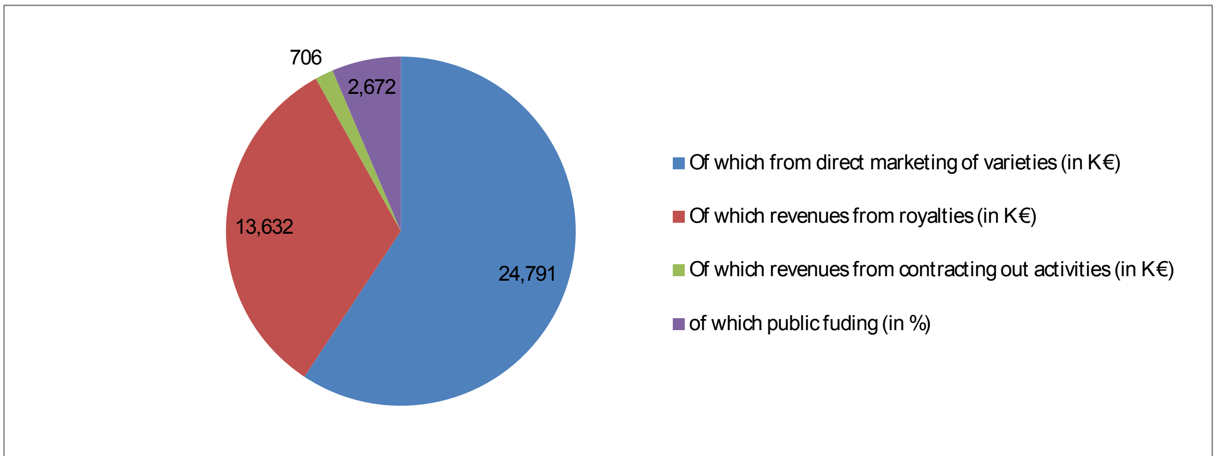
*Revenues*

Resource for public plant breeding programmes can be funded from several complementary sources:

- Public funding: Financial resources that directly come from public research budgets ;
- Contracting out activities: incomes that directly come from selling varieties and technologies to private seed companies ;
- Royalties from selling of varieties: incomes that originate from royalties paid by private commercial partners to public entities based on seed volumes sold. Numerous royalty systems exist and they can be applied on new cultivars or on new breeding technologies. The main scheme consists of royalties that are paid for certified seed in all European countries by the seed producing companies and are included in the price the farmer has to pay for the certified seed. In cereals, the levels are very different and go from €15-€20 per tonne of seed for older varieties in southern and eastern Europe up to €60-€80 per tonne in western and northern Europe. As an average €40-€50 per tonne can be calculated. For varieties that are marketed abroad the royalty usually is split 50:50 between the breeder and the local representative (breeder or seed producing company)[42] ;
- Direct marketing: revenues obtained from direct selling of varieties.

Respondents to the survey reported total yearly revenue of near 42 million Euros of which 31 million are generated by IHAR in Poland. Most of these figures are estimates. In some MS (e.g. DE, the UK), public breeders don't know the level of revenue generated by their varieties because these revenues are allocated to the national budget and not to the breeders' budgets. In others such as BE and the NL, these revenues are estimations as details were not known by the respondents to the survey.

**Figure 13 – Distribution of funds of public breeders (in K Euros)(2010)**




*Source: Survey results*

About 5 % of the total budget is coming from public funding (2.7 million Euros). The main source of revenues is the direct marketing of varieties. Revenues from royalties are estimated at about 30 % of the total revenues (13. 6 million Euros).

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[42] Different models to finance plant breeding. Proceedings of the ECO-PB International Workshop on 27 February 2007 in Frankfurt, Germany. European Consortium for Organic Plant Breeding, Driebergen/Frankfurt. A.M. Osman, K- J. Müller, K- P. Wilbois (Eds). 33 pp.

Revenues generated by the selling of activities to other public institutes or to private partners are marginal.

**Table 19 – Importance of public funding in the total revenues of public plant breeding by MS (2010)**

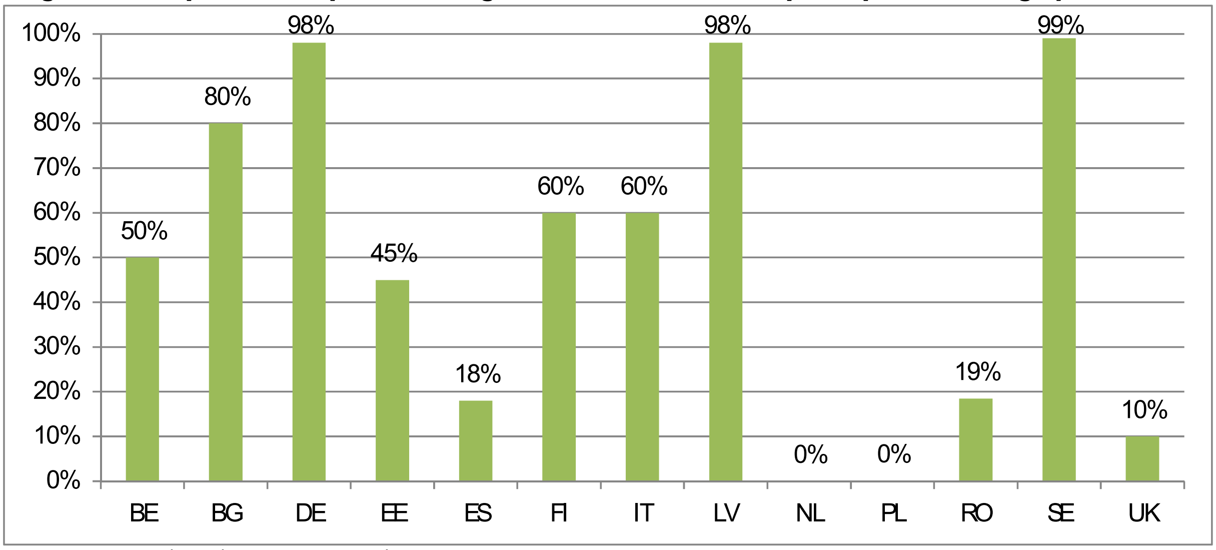
| Period | EU 27 MS (in which public breeding occurs) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BE | BG | DE | EE | ES | FI | IT | LV | NL | PL | RO | SE | UK |
| Total revenues | 1,000.0 | | Unknown | 2,224.0 | 2,900.0 | 83.0 | 330.0 | 209.0 | 1,000.0 | 31,250.0 | 2,800.0 | 5.0 | Unknown |
| *of which public fuding (in %)* | *50%* | *80%* | *98%* | *45%* | *18%* | *60%* | *60%* | *98%* | *0%* | *0%* | *19%* | *99%* | *10%* |
| *Evolution public funding (2000-2010)* | ↘ 25% | ↘ | | ↗ 10% | ↗ 54% | ↘ 50% | ↘ 50% | ↗ 23% | ↘ 100% | ↘ 100% | ↗ 54% | = | ↘ ↘ |

*Source: Survey results. Evolution is based on qualitative assessment by respondents to the survey questionnaire. Bulgaria: 2004-2005 data*

In the majority of MS, public funding remains the main source of financing. In the NL and at IHAR in Poland, the government no longer funds public plant breeding efforts. Resources must be found in the private sector. Four MS (EE, ES, LV, and RO) highlighted that the percentage of public funding in the total resources is increasing, by 10% in EE to by 54% in ES and RO. FR has not reported any figures.

When an increase of public funding is observed in all NMS that have provided figures during the survey, a decrease is observed in all EU 15 MS to the exception of Spain in which an increase of public funding is reported as highlighted before.

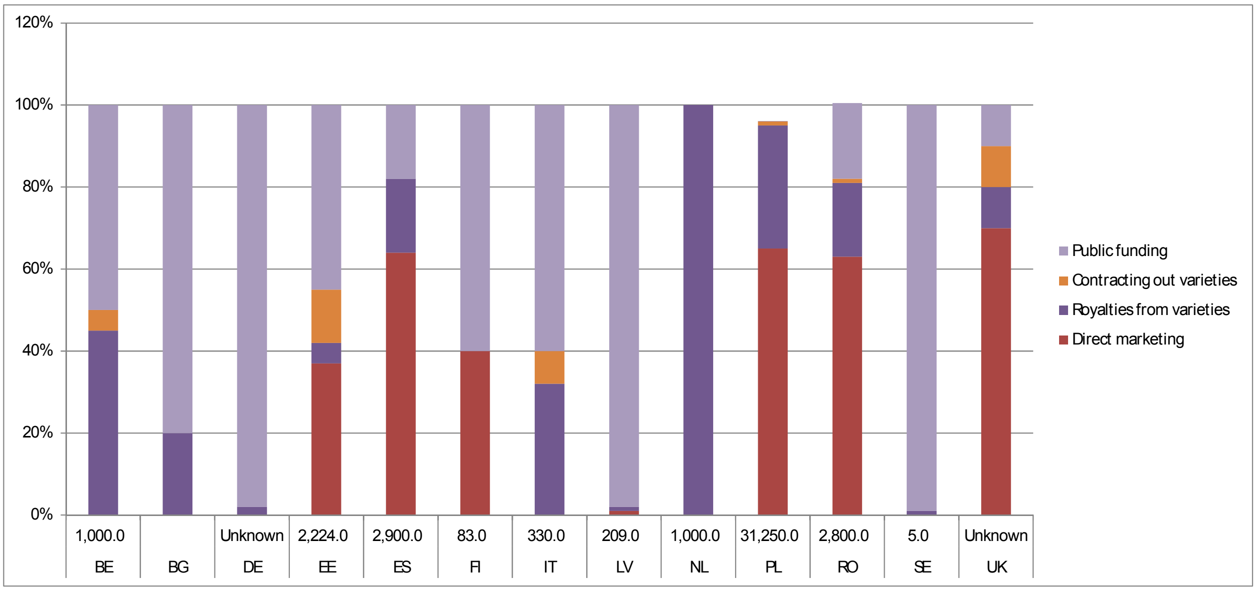
**Figure 14 – Importance of public funding in the total revenues of public plant breeding by MS (2010)**




*Source: Survey results. Bulgaria 2004-2005 data*

Revenue sources for public breeding largely depend of the national strategy regarding agricultural research as a whole. For example, most of the agricultural research in the NL is based on a cost recovery mechanism based on partnerships with private partners and additional funding (e.g. EU funding). In the NMS, direct funding from the government remains the main funding source for public breeders.

**Figure 15 – Source of budget in public plant breeding by MS (in % of total budget)**




Revenues from direct marketing of varieties are important in a small number of MS (EE, ES, FI, PL, RO, and the UK). In each of these countries, to the exception of FI, a dual approach based on direct marketing and on a royalties system is combined and is developed on a crop by crop basis.

## Public/private partnerships

Public and private sector plant breeding have coexisted in industrialised countries over the past 100 years, i.e. since the beginning of modern scientific plant breeding (Heisey, 2003). Since the end of World War II, privatisation of the public sector has occurred in Western Europe and is currently on-going in the EU 12 MS even if a few MS still have robust public breeding capacities (e.g. RO, PL). Therefore the question on the role of public breeding arises.

Parameters defining the relative roles of public and private plant breeding have varied by region, country and crop and have also changed over time. Today a large variability in the dominance of private breeding per crop and region is observed.

**Complex mechanisms of public/private partnerships have developed in a large majority of EU countries**.

The major trend considers that public funding is dedicated to perform activities not run by the private sector as they require deep scientific expertise not yet widely present in the private breeding industry. This is the case for the novel technologies that have developed during the last 30 years (e.g. acceleration of biology applicable to plant breeding based on molecular techniques).

Under this trend, the public sector concentrates on providing services to selected commercial breeders or in the production of services and breeding results that can be considered as public goods.

The majority of respondents to the survey have mentioned being involved in PPP projects. They provide a description of the partnership but they do not detail the financial agreements and the distribution of the funds. Each of these PPPs is very different in nature, objectives and level of resources involved. Additionally, the large majority of these PPP include pre-breeding and genomic activities which are the main activities covered by the agreement. **The applied plant breeding part is only a small part of the PPP programme which in a large majority of cases is performed by private breeders**. Therefore it is difficult to summarise efforts and resources involved in the development of new varieties through these projects.

Instead we present the main examples of PPP projects that were collected during the study.

**Pre-breeding programme in perennial ryegrass in Nordic countries**

Breeding of perennial grasses is a long-term activity that requires many years of pre-breeding and use of germplasm until the release of improved cultivars. Perennial ryegrass, which is the main forage grass in Denmark and southwards in Europe, is at present reaching the adaptation border when grown north of a line from Oslo to Helsinki. It is expected to expand further north due to milder winters and shorter periods of snow coverage. In preparation for the predicted climate changes, this PPP pre-breeding programme is aimed at selecting plant materials of perennial ryegrass for the development of cultivars with a suitable adaptation to future climates in Nordic countries. The main challenges are susceptibility to low-temperature pathogens, inadequate growth stop in the autumn to allow for sufficient cold hardening and winter survival, with low persistency as the result.

This project is part of the Public Private Partnership for Pre-breeding programme, set up in 2011 by the Nordic Council of Ministers, to support the development of Nordic plant breeding satisfying the long-term needs of the agricultural and horticultural industries, specifically regarding adaptation to climate change; targets for environmental policies; and demands from consumers & markets.

More info:

***http://www.nordgen.org***

*Source: Nordgen*

**PPP on plant biotechnology of the future**

The national public and industry funded Research Program 'GenomAnalyse im BIologischen System Pflanze' was initiated by the German Federal Ministry for Education and Research (BMBF) in 1999. After three phases of funding GABI 1, GABI 2, GABI FUTURE, the Initiative Plant Biotechnology of the Future started in 2011. Within the Plant Biotechnology of the Future phase, public-private industry-driven and application-oriented consortia – 68 public institutions and 44 industry partners - are working on 25 projects focused on the thematic: field quality, sustainability and harvest. More info: www.gabi.de

Source: BDP-GFP

**PPP French Stimulus Initiative "Investissement d'avenir" on wheat breeding: BREEDWHEAT**

This is an investment of 9 M€ for a long-term project on wheat genomics. The public-private project will combine genome sequence-based tools and new methodologies for breeding wheat varieties with improved quality, sustainability, and productivity. In total, 39 M€ are being invested over 9 years by 26 French partners, including 11 private companies, to develop and use efficient genome sequence-based tools and new methodologies for breeding wheat varieties with improved quality, sustainability, and productivity. The project aims at sequencing of the wheat chromosome and detection of new structural polymorphisms. 5000 wheat lines from INRA genetic stocks will be extensively characterized and used to identify new alleles to support a pre-breeding program aimed at developing varieties that can be directly exploited by breeders. The efficiency and economic impact of various selection schemes will be assessed in a farm-scale breeding program. A robust bioinformatics platform enabling efficient association analyses and breeder friendly access to the data will also be established.

*Source: INRA*

**The PPP BBSRC programme in the UK.**

In the UK, plant breeding activities for cereals and pulse crops developed by the Plant Breeding Institute were recognised in Europe at large before they were privatised in 1997. Through the Biotechnology and Biological Sciences Research Council (BBSRC), the UK has re-established research capacities mainly in the field of genomics and biotechnology. For example a five-year partnership of more than €10 Million between BBSRC, the Scottish government and a consortium of 14 leading companies aims at supporting innovative and excellent research to underpin the development of improved crop varieties that deliver increased productivity and consistent, high quality end products. This project called Crop Improvement Research Club (CIRC) aims at developing crop varieties with greater yield potential and the ability to deliver this sustainably with reduced

inputs and without detrimental effects on the local ecosystem. Equally, new crop varieties are required that reliably and consistently produce high quality products that are safe, nutritious and meet end-user requirements.
*Source: FERA*

The analysis of the structure of the existing PPP shows that the majority of the partnerships includes all plant breeding activities (from genomics to release of varieties). Public universities continue to play a critical role in providing basic scientific expertise and education required by private breeders. Their efforts are concentrated at genomic and pre-breeding levels. Results are then transferred to private actors for the variety development end variety testing phases. Assuming a continuation of current downward trends in public investment in agricultural research and education and taking into consideration that the global breeding industry is becoming increasingly concentrated, innovative funding arrangements will be needed to ensure the financial sustainability of plant breeding programmes in public institutes and universities. This is particularly the case for the EU 15 MS institutes that have already delegated variety development and variety commercialisation of varieties to the private sector. In the EU 12 MS public institutes have kept their capacities in seed production and in M&S and therefore revenues allows the financing of their research activities. IHAR in Poland and Zseged in Hungary are the main key examples of that model.

However, the long term economic sustainability of these institutes and their capacity to stay competitive on the market place has to be demonstrated. One may consider that public plant breeding institutes will have more difficulties to sustain than universities. Unlike universities, which can argue that genomic and pre-breeding is a public good requiring public funding, public plant breeding institutes will have more difficulties convincing policy makers that their activities cannot be picked up by private companies. To get a chance to be convincing enough, public breeding programmes have to move upstream in the research scheme and concentrate on genomic, pre-breeding and on basic germplasm improvement activities and methodological development work, leaving to the private sector more applied type of work (development of cultivars with good local adaptation) (Morris et al., 2006).

This approach requires that effective collaboration mechanisms are developed in which all partners have to deal with the IP dimension of the research. Issues related to technology ownership and confidentiality will become of increasingly important.

The majority of PPP that have been recently been established are all moving in that direction as illustrated by the examples presented in the above mentioned text boxes.

One may consider that an additional way of developing PPPs in the EU would be based on the EU funding scheme via its Knowledge Bio Based Economy (KBBE) cooperation programme. However as the EU strategy is to fund upstream research rather than applied research only upstream activities receive financial grants from the European Commission. Then, research work that is initiated in these KBBE projects can be continued outside the funding scheme by the same actors if other type of funding is available. The ExpResBar project can be mentioned here as an example of this approach: this plant-KBBE project (2010-2013), involving a consortium of public research groups from organisations in Germany and Spain, and private seed companies from Germany, Spain and Denmark, has the objective to discover barley germplasm with good disease resistance (powdery mildew and scald) and to incorporate it into breeding programs. This project will not lead to the development of new cultivars but to the development of improved populations that could then be taken over by the private sector based on backcrossing programmes with MAS to introgress powdery mildew and scald resistance on material of interest.

These two approaches highlight that public breeders will further concentrate on upstream activities and will further delegate variety creation to the private sector.

### 4.2.2 Evolution of the number of public maintainers in the EU 27 MS in agricultural and vegetable crops

This additional analysis was carried out to complement the results of the survey.

Article 17 of Commission Decision 2004/842/EC[43] specifies that each Member State shall notify the Commission and other Member States of the grant of an authorisation for placing on the market of seed belonging to varieties for which an application for entry in the national catalogue of varieties of agricultural plant species or vegetables has been submitted. All these notifications are listed in the so-called Common Catalogues (CC) of varieties of agricultural crops and vegetable species. As soon as they are listed in the CC varieties can be marketed in the entire EU. Each of the listed variety needs to be multiplied, "maintained"[44] by a national representative.

Common Catalogues do not exist for all crop species that are grown in the EU. However with about 150 crop species, the research team considers that the CC includes more than 95% of the bred crop species on which plant breeding activities are carried out in the EU.

Maintenance of a variety consists of multiplying a sample of the true variety (breeder seed) to be delivered to the seed multiplication units in charge of parental and commercial seed production. A maintainer is required in each country for each variety listed in the national catalogue. The CC list all varieties registered in the EU but also list maintainers per MS.

On the basis of these lists of maintainers in the CC, the research team analysed the evolution of public maintainers during the last 10 years as a way to study the evolution of public plant breeding capacities in the EU. This section presents the main results of this analysis.

The main objective of this complementary analysis is to identify the importance of the public sector via the number of public maintainers. What is the long term trend on term of number of public maintainers? To what extend are the results of this analysis correlated to the results of the survey?

Two specific periods were considered:

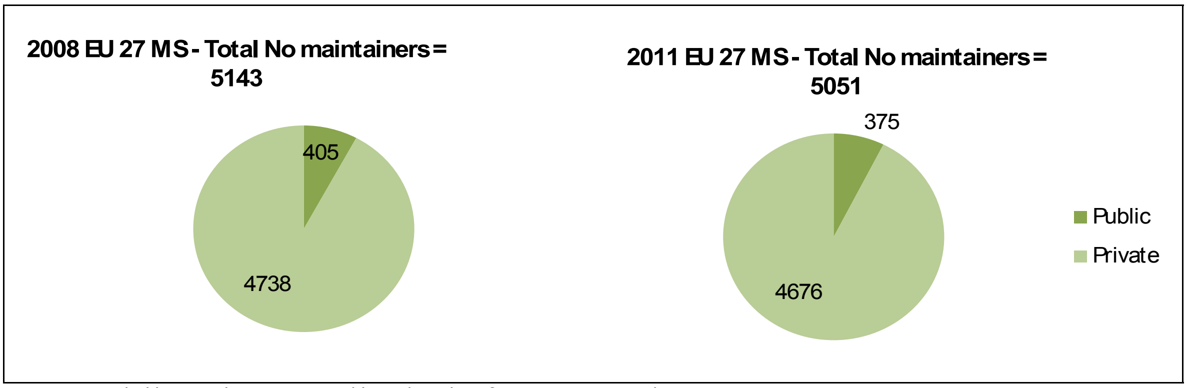
- 2001 to 2011 for the old MS that were part of the EU in 2001 (EU 15 MS); and
- 2008-2011 for the new MS that joined the EU in 2004 and 2007 (EU 12 MS) as 2008 is the first year when EU CC with 27 MS were published by the Commission.

The two Common Catalogues list 5,051 national maintainers in 2011. Over the 2008-2011 period, the total number of public maintainers remained stable (reduction of 92 national public maintainers on a total of 5,143 in 2008). Public maintainers represent only 7% (375) of the total.

[43] Commission Decision of 1 December 2004 concerning implementing rules whereby Member States may authorise the placing on the market of seed belonging to varieties for which an application for entry in the national catalogue of varieties of agricultural plant species or vegetable species has been submitted (notified under document number C(2004) 4493)Text with EEA relevance

[44] See definition of a maintainer in the glossary in Annex 1

**Figure 16 - Number of maintainers in the EU for agricultural & vegetables species (2008-2011)**




*Source: compiled by Arcadia International based on data from Common Catalogues*

The breakdown of the statistics per group of crops and type of maintainers is presented in the following table.

**Table 20 - General statistics on number of maintainers in the EU 27 MS**

| | 2008 | 2011 |
|---|---|---|
| **Total number of maintainers** | **5143** | **5051** |
| *Of which for agricultural crops* | *3979* | *3730* |
| *Of which for vegetable crops* | *1164* | *1321* |
| | | |
| *Of which private maintainers* | *4738* | *4676* |
| *Of which public maintainers* | *405* | *375* |
| | | |
| **Public maintainers** | **405** | **375** |
| *Of which from EU 12 MS* | 163 | 163 |
| *Of which from EU 15 MS* | 242 | 212 |
| | | |
| *Of which for agricultural crops* | 309 | 269 |
| *Of which for vegetable crops* | 96 | 106 |

*Source: compiled by Arcadia International based on data from Common Catalogues*

Most of the EU 12 MS have a long history of public plant breeding and therefore the total number of public maintainers from the NMS contributes to nearly 40% of the total. In the EU 15 MS, the number of public maintainers has remained stable since 2001. The increase that is observed in 2008 is due to the enlargement and a greater exchange of varieties between old and new MS. In 2008, all varieties that were listed in national catalogues of NMS have been added to the CC and therefore a new market opened for them. National maintainers for these new EU varieties were needed leading to this increase of the number of public national maintainers.

The number of public national maintainers is based on registration of varieties per MS given that, as requested by the EU Marketing Directives, a national maintainer is mandatory. A public organisation can be a national maintainer for several crops/varieties, therefore the number of EU public organisations that release varieties in the EU is lower than the statistics presented above.

In 2011, the CC list 222 individual public organisations in the EU 27 MS.

**Table 21 - General statistics on number of public organisations in the EU 27 MS**

| | 2008 | 2011 |
|---|---|---|
| **Total number of public organisations acting as maintainer** | **209** | **222** |
| ***Of which for agricultural crops*** | *148* | *147* |
| ***Of which for vegetable crops*** | *61* | *75* |
| | | |
| ***Of which in the EU 12 MS*** | *97* | *100* |
| ***Of which in the EU 15 MS*** | *112* | *122* |

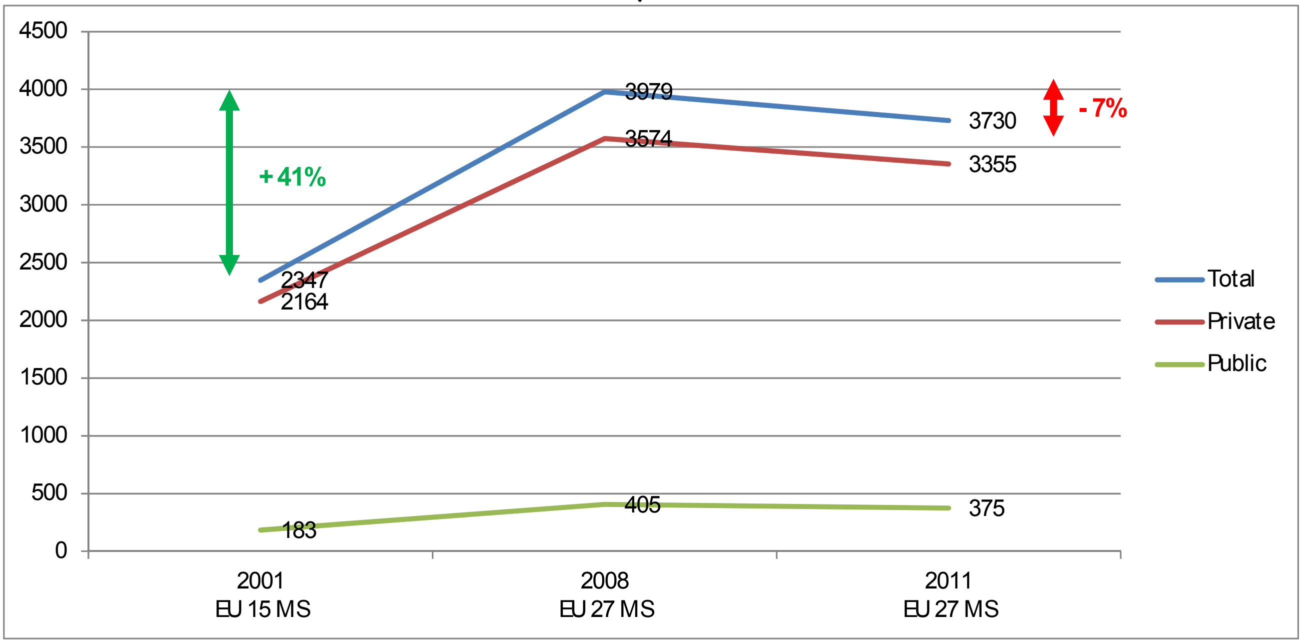
*Source: compiled by Arcadia International based on data from Common Catalogues*

The evolution (+13) over the 2008-2011 can be explained by the EU enlargement as explained above linked to the reorganisation of the marketing scheme (new seed distributors). As suggested, these statistics must be considered carefully and a minimum of 5-10 years is necessary before making clear assessments in the evolution of public organisations releasing and maintaining varieties.

## Agricultural crops

The Common Catalogue of agricultural species includes 80 crop species (cereals, fodder plant, beet, seed of oil and fibre plants). Potatoes, vine, ornamentals and fruit plants are not included in this catalogue. An increase of 41% of the total number of maintainers was observed at EU enlargement in 2004. Since 2008, the number of maintainers has decreased by 7%.

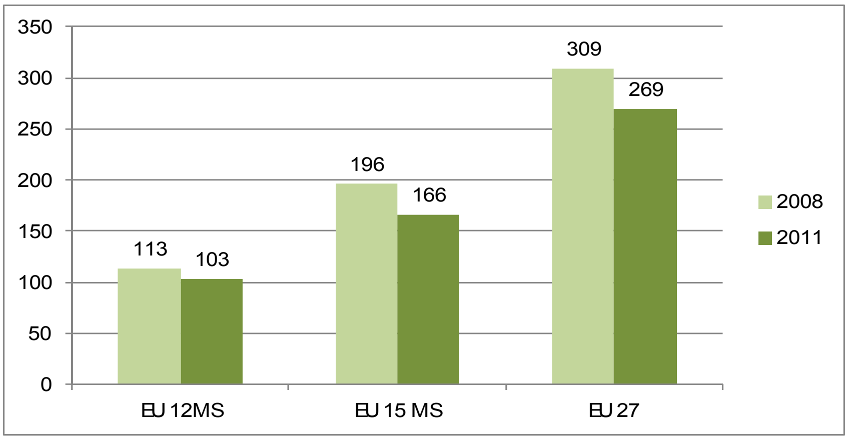
**Figure 17 - Evolution of the number of maintainers in agricultural crops in the EU (2001 – 2011)**




*Source: compiled by Arcadia International based on data from Common Catalogues*

Data that presented above hide the large variability that exists between MS as can be observed below. In MS where plant breeding is a well developed sector, the importance of the public domain remains marginal (less than 15%) in terms of number of national maintainers. The total number of public maintainers has decreased by 40 ( -13%) over the last three years equally balanced between EU 12 MS and EU 15 MS.

**Figure 18 - Evolution of the number of public maintainers for agricultural crops (2008-2011)**



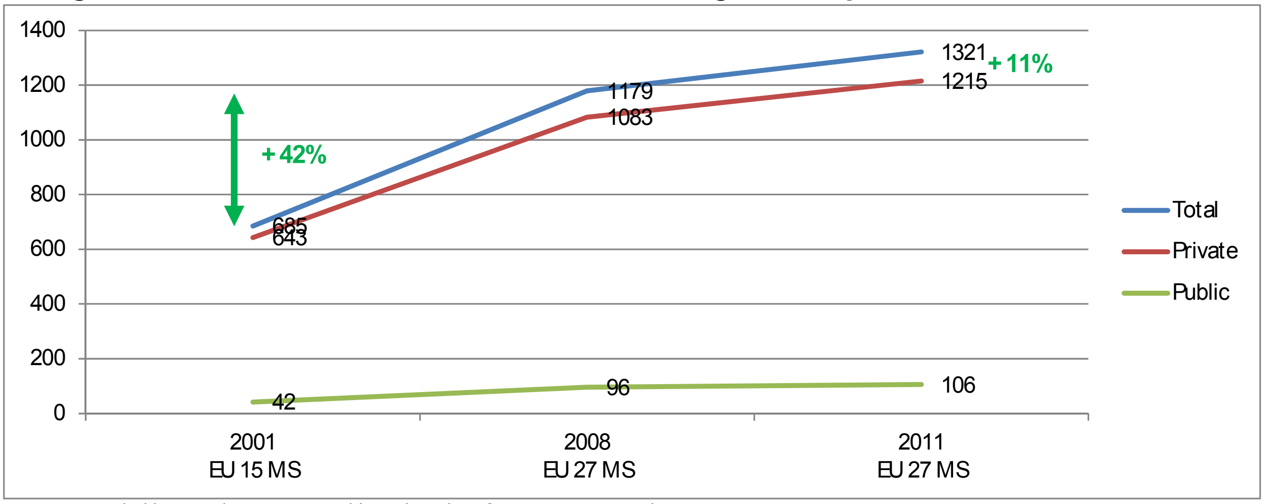

*Source: compiled by Arcadia International based on data from Common Catalogues*

## Vegetable species

The situation in the vegetable sector shows a different profile.

The Common Catalogue of vegetable species listed 685 maintainers in 2001, when the public breeding sector contribution was of 6%; in 2008 the total number of maintainers nearly doubled (1165 maintainers) and the contribution of the public sector slightly increased to 8%. In 2011 the number of maintainers increased by 11% compared to 2008 (total of 1321 maintainers) and the importance of the public sector remained at 8%.

**Figure 19 - Evolution of the number of maintainers in vegetable crops in the EU (2001 – 2011)**

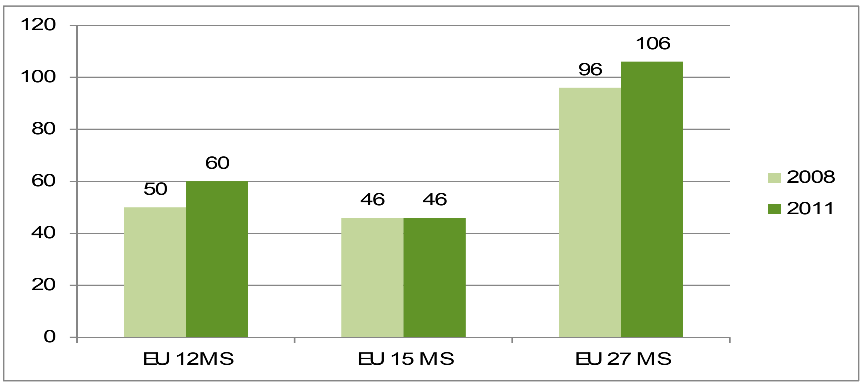



*Source: compiled by Arcadia International based on data from Common Catalogues*

The total number of public maintainers has increased by nearly 10% over the last three years. This increase is observed in the NMS only. This evolution is certainly due to the fact that public institutions from countries that joined the EU in 2004 and 2007 experienced a market expansion to the entire EU.

A second major difference with agricultural crops is based on the fact that more public maintainers are listed in the NMS than in the EU 15 MS. The vegetable sector experienced a rapid consolidation in West Europe during the 2000s. Vegetable seed companies became larger and increased their budget dedicated to breeding with the consequence that public institutes became less competitive. This consolidation started in the new MS at EU enlargement and consequences of the consolidation are not yet visible in the statistics.

**Figure 20 - Evolution of the number of public maintainers for vegetable species (2008-2011)**




*Source: compiled by Arcadia International based on data from Common Catalogues*

In conclusion, this complementary analysis shows that the total number of public maintainers is low ( 7 % of maintainers are public maintainers) of which NMS contributes to nearly 40% of the total. In the EU 15 MS, the number of public maintainers has remained stable since 2001. The increase that is observed in 2008 is due to the enlargement and a greater exchange of varieties between old and new MS. In agricultural crops, an increase of 41% of the total number of public maintainers has been observed at enlargement in 2004. Since 2008, the number of maintainers is decreasing by 7%. The current situation in the vegetables sector shows a different profile. The 2004 enlargement has brought a large number of maintainers to the EU as the total number of maintainers has nearly doubled, with 1165 maintainers and the contribution of the public sector has slightly increased to 8%. In 2011 the importance of the public sector remains flat at 8%.

These results confirm the results of the survey results as the importance of the public plant breeding sector is low and declining over time. This trend is not (yet) visible in the vegetable sector as consolidation in that sector started after consolidation in the agricultural sector. Consolidation led to divestment of the public sector and then to reduction of the number of public breeders and of public maintainers, but as varieties can be listed on the CC for more than 20 years, effects of reduction of public plant breeding efforts are not yet visible in vegetable crops.

## 4.3 Analysis of the potential of public plant breeding to fulfil the needs of the EU sustainable bio-based economy until 2020.

The question of whether or not the current public and conventional plant breeding sector can fulfil the needs of the EU sustainable bio-based economy until 2020 raises several comments:

- The plant breeding needs that have been inventoried and categorised under chapter 3 do not consider the political evolution, e.g. evolution of the CAP and strategy regarding bio energy and bio fuels. First-generation biofuels competing with food crops are not sustainable. Agro-bioenergy in general does not match the criteria of sufficiency. Arable land resources are limited and further expansion into forests, grassland and woodland areas will result in more carbon emissions, which offset the primary justification for using biofuels. The main challenge for commercial second- generation biofuels is to develop conversion technologies at industrial scale and at competitive prices that do not use primary biomass but rather waste and residues from the food and feed production chain. These technologies, still at the laboratory experimentation and testing stages, require large scale feedstock supplies and pose logistical and sustainable management challenges[45];
- Plant breeding is a multidisciplinary process that takes between 8 to 10 years from the initial crosses and the commercial release of the variety. Additionally, several years are required to have a full commercial deployment of varieties containing new traits at a significant scale. These time constraints lead to the conclusion that traits that were not integrated in public plant breeding programmes in 2005 cannot really contribute to the 2020 strategy as the results will be visible later thereafter ;
- For the last 15 years, breeding process can be accelerated by new technologies leading to the point that conventional plant breeding including field activities is no longer a must for releasing new varieties including new traits. A new trait can be identified in laboratories and then directly introgressed into existing germplasm via backcrossing. Public scientists will contribute to a certain level to fill the needs of the bioeconomy 2020 but as these approaches are based on genomic and pre-breeding activities, they do not fall under the scope of this study. Therefore conclusions that are presented below must be completed with an assessment of the importance of the role of the public scientific community in upstream R&D process line.
- **Several public/private partnerships that were recently initiated are concentrating on pre-breeding activities but the general approach is to complete the R&D to the development of new cultivars in partnership with one or several private seed companies.** Therefore conventional

[45] SCAR report 2011

breeding activities will be developed under these programmes when progress is being observed in the pre-breeding phases. This is for example the case of the BBSRC project in the UK. In 2005, 89% of Government funding on plant genetic improvement is on basic research, and only 11% on applied breeding[46]. A shift of funding will be observed when first tangible results are released. This approach certainly means that when linked to fundamental research, public plant breeding funding will increase and further PPPs will be developed. To date, this evolution is not yet visible in the data collected during the study.

- According to stakeholders from the plant breeding community and also highlighted by the Nordic Council of Ministers in its proposal to promote Nordic plant breeding[47] plant breeding companies are only prepared to collaborate in practical plant breeding in agricultural crops on a bilateral basis between concerned companies linked to market considerations, also regarding breeding of agricultural species based on public funding.

Against these arguments, the following key conclusions on the past and current public conventional plant breeding capacities can be drawn:

- Representativeness of the respondents to the general survey was good and the research team consider that based on its expertise and knowledge of the sector; it can be estimated at 80-85% of the total public effort.
- Data from Serbia are included as a benchmark of EU public efforts because in this country public breeding is part of public authorities.
- **Eight out of 27 MS do not have at present any public conventional plant breeding activities;**
- **Crops and crop groups subject of public research are largely food and feed crops produced via the main grain commodity market. Very few initiatives are specifically targeting non-food and non-feed crops.**
- **Plant breeding is multidisciplinary by nature. Public efforts are concentrated on germplasm collection and characterisation and on variety development. In a large majority of cases, variety testing is partially outsourced and marketing of varieties (production and sales) is assigned to a seed industry partner. Molecular breeding has been integrated in programmes when technologies can be used in a routine mode.**
- **Less than 1,000 public staff has been inventoried in the public sector conventional breeding of which the majority is located in the Eastern countries.** In each of the main EU seed countries in Western Europe, staff is estimated at 50 FTE or less (a maximum of about 15% of total breeding). Evolution of the number of staff is MS specific and different profiles exist based on public policy on agricultural research.
- **The total financial resources of the public sector are estimated at about 40 million Euros per year for developing new cultivars**. The private plant breeding budget is roughly estimated at 800-900 million euros.
- **The number of varieties released by the public sector is negligible in comparison with the total number of varieties released per year by the private sector.** In eastern countries, target traits are traits leading to an optimal yield (economic) return to growers. In EU 15 MS, it appears that some institutes concentrate on developing other traits of interest, different from those being developed by the private sector. In all cases, the approach is mainly related to improving yield and yield stability and to integrate several abiotic, biotic and quality traits on a crop-by-crop basis. All other traits, with a few

[46] NIAB (2005) UK crop genetic improvement – a new role for NIAB

[47] Nilsson A. et *al.*.2010. Measures to promote Nordic plant breeding. TerraNord 2010:518. Nordic Council of Ministers, Copenhagen, 2010.

exceptions, listed as needs under chapter 3 (see figure 4) are not included as priorities in public and private breeding programmes.

- **Public breeding resources are mainly coming from public funding to the exception of the NL in which the activity is based on a full cost recovery system.** Importance of the ratio of royalties seems to increase in the majority of cases. Very few resources are coming from contracting out activities to either other public entities or private companies.
- **Public/private partnerships are more developed in the EU 15 MS rather than in the EU 12 MS** in which public conventional plant breeders play the role of transferring technology to the market together with a commercial partner. The majority of these PPPs are dedicated to the development of upstream activities.
- **Participatory plant breeding (PPB) is seen as an alternative to the current master scheme by several research institutes and NGOs.** In contrast, the seed industry does not see PPB as a sustainable alternative to the current system. Too few references exist to validate one or the other option, and very few public EU scientists are engaged in these research. In fact, the two schemes don't cover the same agricultural systems and should not be seen as competitors. They are complementary as PPB covers mainly economic sectors in which seed companies have no interest; then, varieties released by PPB are not registered and belongs to an informal system.
- **Public maintainers in the EU 27 MS represent only about 7% of the total number of maintainers. The number of public maintainers is decreasing for agricultural crops (- 7% since 2008) but stable in vegetable crops.**

**On the basis of all these conclusions, it is hard to envisage the public conventional plant breeding sector delivering new varieties, including traits required for fulfilling the needs of the bio-economy strategy 2020 where private plant breeding is not currently investing enough**. In MS (e.g. PL, RO) where public breeders are still relevant competitors, focus is put on agronomic traits only. In the other MS, public breeders appear complement the private sector, in particular in relation with the PPPs that are mainly based on genomics and pre-breeding activities.

# ANNEX 1: GLOSSARY OF CONVENTIONAL PLANT BREEDING

***Note:*** *glossary compiled from several sources and in particular from:*

- *The OECD web site ;*
- *Open plant breeding foundation (**www.opbf.org/glossary/**). The original glossary was adapted from The Amateur Plant Breeder's Handbook by Dr. Raoul A. Robinson. A free download of the handbook is available from **www.sharebooks.ca** ;*
- *Schlegel, Rolf H. J. Dictionary of plant breeding / author, Rolf H.J. Schlegel. -- 2nd ed. p. cm. Previous ed. published under title: Encyclopedic dictionary of plant breeding and related subjects. ISBN 978-1-4398-0242-7 (alk. paper) ;*
- *Schlegel, Rolf H. J. Encyclopedic dictionary of plant breeding and related subjects.*

**Allele**

The alternate copies of a single gene. Each gene normally consists of two alleles. Each allele occurs on one of the two matching chromosomes, one of which comes from the male parent, and the other from the female parent. In one individual, the two alleles may be both dominant (AA), both recessive (aa), or one of each (Aa). The first two of these combinations are described as homozygous; the third is heterozygous.

**Allogamy**

Greek; allo = other, or different; gamy = marriage. The term means cross pollination. An allogamous plant or species is one in which cross-pollination is normal or even obligatory. Cultivated allogamous species include maize, sorghum, millets, and rye; members of the onion family, members of the cucumber family; and various pulses and vegetables.

**Allopolyploid**

A polyploid has more than two sets of chromosomes (e.g., triploid, tetraploid). In an allopolyploid, the chromosomes are derived from two or more different species. In an autopolyploid, all the chromosomes are derived from the same species.

**Analogous evolution**

Evolution in which similar features have different origins (e.g., the wings of birds, insects, and bats represent analogous evolution). This is the converse of homologous evolution, in which similar features have a common origin (e.g., all the plants in one family have a common ancestor).

**Apomixis**

Greek: apo = without; mixis = mixing. Asexual reproduction by seeds produced from the maternal tissue of a flower. Apomictic seeds occur mainly in grasses, and they have the advantage of being the equivalent of vegetative propagation, being free of most vegetatively transmitted diseases (particularly viruses). The so-called 'apomictic gene' is a topic of interest among molecular biologists because it could very easily preserve agricultural characteristics, including hybrid vigour, in heterozygous seeds of open-pollinated crops.

**Autogamy**

(Greek: auto = self; gamy = marriage). Self-fertilisation, or self-pollination. An autogamous species is one in which individual flowers, or plants, are fertilised with their own pollen. However, some cross pollination always occurs in an autogamous species and variability is always maintained. (See also: allogamy).

**Back-crossing**

A Mendelian breeding technique designed to transfer a single gene, usually a resistance gene, from a wild plant into a cultivar. The cultivar and the wild plant are cross pollinated to produce a hybrid progeny. A hybrid individual that carries the resistance gene is then back-crossed with the cultivar parent to produce a second breeding cycle. This process of back-crossing is repeated for several breeding cycles until the hybrid is indistinguishable from the cultivar parent, except that it carries the resistance gene from the wild parent. Back-crossing is an excellent technique when breeding for vertical resistance, but that it dilutes polygenically inherited characters, and it should not be used when breeding for horizontal resistance.

**Biological control**

The control of crop parasites that is exerted by predators, hyper-parasites, competitors, antagonistic organisms, and other agents. The effects of this control can be diminished or lost entirely by the use of crop pesticides. This loss of biological control that occurs with pesticide use is called biological anarchy. The proponents of integrated pest management (IPM) rely on restoring lost biological controls. These losses may be more important than many people realise. They also suggest that we may need rather less horizontal resistance than we may think in order to obtain a complete control of crop parasites, because the biological controls will be restored once pesticide use stops. The best means of restoring biological control is by the use of horizontal resistance; and the best means of enhancing horizontal resistance is by restoring biological control. The two effects are mutually reinforcing.

**Biomass**

The total weight of one or more named organisms within a particular area.

**Breakdown of vertical resistance**

A total, qualitative failure of vertical resistance resulting from a matching allo-infection. Being matched, the vertical resistance stops functioning, and it is said to have broken down. In a wild pathosystem, which has genetic diversity, breakdowns occur only in individual host plants. In a crop pathosystem, which has genetic uniformity, the breakdown involves the entire cultivar, because every allo-infection, from plant to plant within that crop, is a matching infection. Because some matching always occurs, vertical resistance is temporary resistance. Because horizontal resistance operates against matching pathotypes of the parasite, it does not break down in this way; it is durable resistance.

**Breeders' rights**

The plant breeders' equivalent of authors' copyrights. These rights earn royalties on the sale of seed of registered cultivars. The breeders' rights legislation in most countries has a further clause that entitles a breeder to use a registered cultivar in their breeding program. However the regulations under the plant patent legislation of the USA is considerably different in this respect.

**Breeding cycle**

The complete cycle of events that constitutes one generation of plant breeding. A breeding cycle usually begins with the cross pollination of selected parents, and ends just before the next cross-pollination is due. There may be several intervening generations which may include a multiplication generation, single seed descent for several generations, and, perhaps, late selection to produce the new parents of the next breeding cycle in an autogamous species.

**Bulk screening**

A technique for obtaining a fair degree of homozygosity for the purposes of late selection. A heterozygous population of an inbreeding species is multiplied for several generations in the field with minimal or zero selection in the early stages. Such early selection as does occur involves only single gene characters such as marker genes. However, single seed descent in a greenhouse is usually preferable, because it is faster.

**Certified seed**

Seed can be certified in a number of ways. True seeds can be certified with respect to their identity, purity, trueness to type, freedom from diseases, and germination percentage. Plant parts used for vegetative propagation (e.g., tubers, setts, rooted cuttings) are often certified in the same way.Note that a cultivar that requires seed that is certified free from disease is usually very susceptible, otherwise such certification, which is expensive, would not be necessary. One of the many objectives of amateur plant breeding is to develop horizontal resistance to the point that certification for freedom from disease is no longer required.

**Common catalogue**

A catalogue of varieties of agricultural plant species, these catalogues are established on the basis of information received from EU Member States. They list those varieties whose seed is subject to no marketing restrictions within the EU as regards variety. Varieties must meet standards, notably pertaining to distinctness, uniformity, stability and, in the case of agriculture, value for cultivation and use (VCU) in order to be listed.

**Crop architecture**

The shape of crop plants and, hence, the nature of the crop itself. For example, the bean varieties of one species may have either the determinate habit, or they may be climbing vines. The latter are useful for climbing up maize plants in mixed cropping, while the former are more suitable as a pure stand, and for mechanical cultivation and harvesting. Some crops, such as potatoes, can be densely planted in order to cover the ground completely, in order to control weeds.

**Crop pathosystem**

An agricultural plant pathosystem in which people have changed the natural mechanisms of self-organisation. The host, the parasite, and the environment have all been altered by the activities of agriculture. A crop pathosystem is normally characterised by genetic uniformity, and genetic inflexibility. If it is derived from a continuous wild pathosystem, it will not have any vertical resistances; if derived from a discontinuous wild pathosystem, it may have vertical resistances.

**Crossing generation**

In recurrent mass selection, a plant breeding cycle may involve several generations. The crossing generation is the one in which cross-pollination occurs.

**Cross-pollination**

Fertilisation with pollen coming from a different plant. When cross-pollination involves two genetically different plants, it leads to heterozygosity.

**Cultivar**

A cultivated variety, which has originated and persisted under cultivation, as opposed to a botanical variety, which is a component of a wild species. A cultivar is usually a pure line, a clone, or a hybrid variety, and it is genetically uniform, and genetically inflexible. A cultivar consequently cannot respond to selection pressures during cultivation.

**Dominant character**

A genetic character is described as dominant when its controlling allele eclipses the recessive allele.

**Drought resistance**

The ability of a plant to withstand drought. This property can be very valuable in areas of uncertain rainfall. For example, sorghum has greater drought resistance than maize, and is grown in many semi-arid areas for this reason.

**Distinctness, uniformity, stability (DUS)**

The criteria, in addition to variety denomination, on which a plant variety right is determined. DUS testing and variety denominations are required for plant variety protection and for listing and certification.

**Female sterility**

Some crops (e.g., banana) do not produce true seed because of a female sterility. However, male sterility is much more common, and is more useful in plant breeding as a technique for achieving cross-pollination.

**Fertilisation**

This term, which is derived from 'fertile', has two meanings in crop science. It can refer to the feeding of crops with compost, farmyard manure or artificial fertilisers; and it can also refer to the sexual fertilisation of a female ovule by a male pollen cell.

**Field trials**

Typically, these are statistical trials carried out under field conditions. Note that statistical trials are very valuable when comparing cultivars, spacing, or fertiliser use for variables such as yield and crop quality. But they can be very misleading when comparing treatments for the control of crop pests and diseases, because of parasite interference.

**Gene**

The unit of inheritance which is carried on a chromosome. An inherited character may be controlled by a single gene (i.e., a Mendelian gene), or it may be controlled by many genes (polygenes).

**Gene banks**

The popular term for collections of plants made for purposes of genetic conservation. A gene bank may consist of collection of seeds, which have to be re-grown periodically, or of an arboretum of tree crops.

**Gene frequencies**

Mendelian breeding emphasises single genes, and gene-transfers by pedigree breeding. Biometricians' breeding emphasises polygenes, and changes in their gene frequencies by population breeding, recurrent mass selection and transgressive segregation. For example, horizontal resistance is a polygenic character, and its level can be increased by increasing the frequency of its polygenes in a single individual.

**Gene pool**

The totality of genes possessed by a population of sexually reproducing organisms.

**Genetic conservation**

The preservation of genetically controlled characters in gene banks, which consist either of stored seeds, or of living museums in botanic gardens and arboretums. The concept of genetic conservation was first developed by Mendelians with respect to vertical resistance genes. It is of relatively minor importance for biometricians, and polygenically inherited characters such as horizontal resistance. However, the conservation of old cultivars is of considerable importance to organic farmers, at least until such time as superior, new, horizontally resistant cultivars become available.

**Genetic diversity**

Genetic diversity means that the individuals within a population differ in their inherited attributes. Wild plant populations are typically diverse. Most subsistence crops in tropical countries are also diverse. But modern commercial crops usually have genetic uniformity. A genetically diverse population has genetic flexibility. A fundamental ecological principle states that diversity leads to stability.

**Genome**

The monoploid set of chromosomes which, in a homozygous plant, occurs in a gamete, and consists of all the genes. A term often used loosely to mean the complete set of genes in a plant.

**Genotype**

The genetic constitution of an organism, as opposed to its actual appearance, which is called the phenotype. The distinction allows for recessive genes and polygenes, which may be present but not expressed because of heterozygosity.

**Genus**

In the taxonomic hierarchy, a genus is a subdivision of a botanical family, and it normally constitutes a number of species. A genus is group of closely related species, which have clearly defined characteristics in common. All plants have two Latin names; the first is the generic name, and the second is the specific name. The adjectival form is 'generic', as in inter-generic hybrid.

**Haploid**

A cell or plant that has only one set of chromosomes. A sex cell (i.e., pollen and ovules in plants, sperm and ova in animals) is normally haploid, and the fusion of two sex cells produces a normal diploid with two sets of chromosomes. Haploid plants can be produced artificially, and their single set of chromosomes can be doubled to produce a doubled monoploid. The terms haploid and monoploid are synonymous.

**Heritability**

The percentage of a plant's quantitative variable that is due to genetics, the remaining percentage being due to environment. For example, a plant may have a zero level of parasitism because the parasite is absent from the area in question. It appears to have 100% resistance. However, if the parasite were present with maximum epidemiological competence, the plant might have a 50% level of parasitism. The heritability of that apparent 100% resistance would then be only 50% (i.e., half of the original apparent resistance is inherited and can be inherited by the progeny, while the other half is an environmental effect that cannot be transmitted to the progeny).

**Heterosis**

The hybrid vigour that is exhibited by the progeny of two inbred (i.e., homozygous) but different parents. This vigour persists for only one generation, and it is the basis of hybrid varieties.

**Heterozygous**

This term refers to a plant whose two parents were genetically different. In plants, the term may refer to a single gene, or to the entire genetic makeup of the individual plant. Heterozygous plants do not 'breed true to type'.

**Homozygous**

In plants, this term may refer to the alleles of a single gene, or to the entire genetic makeup of an individual plant.

**Hybrid**

The offspring of a cross between two different genera, species, or varieties. Note the specialised meaning of hybrid variety.

**Hybrid variety**

A cultivar of an open-pollinated species (e.g., maize, cucumber, onion) which has been produced by crossing two inbred lines. The resulting seed then produces plants that exhibit hybrid vigour, or heterosis. A hybrid variety can be used only once, because the hybrid vigour is largely lost in the second generation. This means that the seed of hybrid varieties is expensive, but the expense is more than justified by the increased yields. Hybrid varieties do not normally need the protection of breeders' rights because the breeder has complete control of the inbred lines.

**Hybridisation**

In plants, the cross-pollination that produces a hybrid.

**Inbred line**

A genetic line of plants that has been self-pollinated for a sufficient number of generations (usually a minimum of six) to produce individuals that are more or less homozygous, and which 'breed true'.

**Inheritance**

Inheritance is described as monogenic when the character in question is controlled by a single gene. Monogenic inheritance is qualitative in its effects and it leads to discontinuous variation in which a character is either present or absent, without any intermediates. Inheritance is described as polygenic if the character in question is controlled by many genes, called polygenes. Polygenic inheritance is quantitative in its effects, and it exhibits continuous variation with all degrees of difference between a minimum and a maximum. All polygenic resistance is horizontal resistance, but not all horizontal resistance is inherited polygenically.

**Integrated pest management (IPM)**

A system of pest management in which every important parasite in a crop is monitored and crop protection chemicals are used only when absolutely necessary. The idea is to minimise the use of crop protection chemicals in order to reduce biological anarchy and to stimulate biological control. IPM is used mainly against the insect parasites of crops, and it is greatly assisted by horizontal resistance.

**Interspecific cross or hybrid**

A hybrid between two species within the same genus.

**Laboratory screening**

When conducting recurrent mass selection, a laboratory screening can often enhance a field screening by determining aspects of quality that are not discernible in the field.

**Landrace**

A cultivated plant population which is genetically diverse and genetically flexible. A landrace can respond to selection pressures during cultivation. The maize crops of tropical Africa, which were so vulnerable to tropical rust, were landraces, and they responded to the selection pressure for resistance. Prior to the discovery of Johansen's pure lines in 1905, most crop varieties in the industrial world were landraces, and most subsistence crops in the non-industrial world are still landraces.

**Maintainer**

The maintainer of a variety is a person or an organisation responsible for maintaining the variety and ensuring that it remains true to type throughout its full life-span and in the case of hybrid varieties that the formula for hybridisation is followed. Maintenance may be shared.

**Maintainer Code**

The maintainer code is a unique alpha-numeric code attributed to each maintainer by the National Designated Authority. The list of maintainers is compiled from the individual countries' lists and comprises the names and addresses, including the country, of each maintainer.

**Male sterility**

A male sterile plant is one that has fertile ovules but sterile anthers and/or pollen. Male sterility can be induced with a male gametocide, or it may be genetically controlled. Male sterility can be useful in plant breeding by forcing inbreeding plants to cross-pollinate.

**Marker gene**

A Mendelian gene that is used to identify the progeny of cross-pollination in an inbreeding species of crop.

**Mass selection**

Often called population breeding, or recurrent mass selection this is the converse of Mendelian or Pedigree breeding. Mass selection requires a population, as large and as genetically diverse as possible, which is screened for the best individuals that are to become the parents of the next screening generation. It is the technique of choice for many-gene characters, and for amateur breeders working with horizontal resistance. The selection criteria can include all aspects of yield, quality, agronomic suitability, and horizontal resistance to all locally important parasites. The assessment of each individual must be relative to the neighbouring individuals and the population as a whole.

**Mendel's laws of inheritance**

Mendel's laws of inheritance were based on his work, but were formulated only after his death. They are not of great interest to amateur breeders working with many-gene characters. The first law states that when two homozygous individuals are crossed, the F1 individuals are phenotypically identical. The second law states that recessive characters that are masked in the F1 of a cross between two homozygous individuals, will reappear in a specific proportion in the F2. The third law states that members of different allele pairs (i.e., Aa and Bb) will assort independently of each other when gametes are formed, provided that the genes are not linked.

**Natural selection**

The selection that occurs naturally within a wild population that is genetically diverse. The selection operates because the most fit individuals reproduce the most, while the least fit individuals reproduce the least. This is the mechanism of natural evolution by survival of the fittest. Note that complexity theory now suggests that the mechanism of evolution is natural selection operating on emergents at all systems levels, and that the systems level of the individual is much less important than was previously thought.

**Open-pollinated crops**

This term is synonymous with cross-pollination. Open-pollinated crops can be divided into those that are obligatory cross-pollinated, and those that have an optional self pollination. It may be generally assumed that cross-pollinated crops do not tolerate inbreeding, otherwise they would be cultivated as pure lines. However, inbreeding is often employed in order to produce hybrid varieties. Many open-pollinated crops are cultivated as clones, because this is the only way of preserving their agriculturally valuable characteristics.

**Pedigree breeding**

The breeding method of the Mendelians, also known as the gene-transfer breeding technique, which usually involves the transfer of a single gene from a wild plant to a cultivar. In practice, this gene usually controls resistance to a parasite, and it confers vertical resistance. The wild plant and the cultivar are hybridised, and the progeny segregate into those which carry the gene and those which do not. The progeny are mostly halfway between the two parents in their yield and crop qualities. The best of the individuals which are carrying the gene for resistance is back-crossed to the original cultivar, with further segregation for resistance. The back-crossing is repeated until the progeny have all the desirable qualities of the original cultivar, as well as the gene for resistance from the wild plant.

**Phenotype**

The observable properties of an organism produced by the interaction of its genotype and the environment. For example, recessive characters are part of the genotype, but they are not expressed phenotypically in the heterozygous state. And the Person-Habgood differential interaction is a phenotypic demonstration of a gene-for-gene relationship, but a genotypic demonstration would require inheritance studies in both the host and the parasite.

**Plant genetic resources**

The reproductive or vegetative propagating material of cultivated varieties in current use and newly developed varieties, obsolete cultivars, primitive cultivars , wild and weedy species, near relatives of cultivated varieties and special genetic stocks (including elite and current breeder's lines and mutants).

**Plant propagating material**

Seeds, parts of plants and all plant material, including rootstocks, intended for the production and reproduction of plants. Plant variety rights The recognition of the intellectual property rights of plant breeders in their varieties. Plant variety rights offer legal protection of a new plant variety granted to the breeder or his successor in title. The effect is that prior authorization is required before the material can be used for commercial purposes.

**Population**

A group of individuals of one species occupying a particular area. A population may be either homogeneous or heterogeneous; or either homogenous or heterogenous.

**Population breeding**

The breeding method of the Biometricians, which is concerned with small improvements in quantitative characters that are genetically controlled by polygenes. Population breeding usually involves recurrent mass selection. Population breeding is easy while Pedigree breeding is technical.

**Qualitative variation**

Genetic variation in which a character shows differences in kind. The character is either present or absent, with no intermediates. This variation is typical of Mendelian genetics. The term 'discontinuous variation' is synonymous.

**Quantitative variation**

Genetic variation in which a character shows differences in degree. The character can be present at any level between a minimum and a maximum. This variation is typical of biometrical genetics. The term 'continuous variation' is synonymous.

**Recurrent mass selection**

The breeding method of the Biometricians, designed to increase the levels of desirable qualities -- which are quantitative variables -- by changing the frequency of polygenes. In each screening generation, the best individuals are selected, and they become the parents of the next screening generation. This process is repeated for as many generations as necessary, but the rate of progress declines dramatically after a few generations.

**Screening**

An essential step in population breeding. A large heterogeneous population is screened to find the best individuals that are to become the parents of the next generation. When breeding for horizontal resistance, the best approach is to let the locally important plant parasites do most of the screening, by spoiling or killing all the susceptible individuals. The holistic approach is to screen for high yield, on the basis that only resistant plants can yield well. All measurements should be relative. That is, only the highest yielding plants are kept, regardless of how poor their yield may be in commercial terms.

**Seed certification**

Seed can be officially certified in various ways. True seed can be certified for identity of cultivar, purity of cultivar, freedom from pests, weeds, and disease, cleanliness, and germination percentage.

**Segregation**

In plant genetics, the term 'segregation' refers to the separation of specified traits within the population of the next generation.

**Selection**

The selection of individuals within a plant population can be positive or negative. Positive selection identifies the individuals to be kept, usually as parents of the next breeding cycle. Negative selection identifies individuals that must be eliminated, or at least prevented from producing pollen, to ensure that they are not represented in future generations. These terms can also be applied to selection within variable populations of tree crops. For example, a cocoa plantation might be suffering from witch's broom disease (Crinpellis perniciosa). A positive selection would identify the most resistant trees for propagation in a new plantation. A negative selection would identify the most susceptible trees for elimination, on the grounds that they were causing severe parasite interference, and their removal would greatly reduce the overall disease incidence.

**Self-pollination**

Fertilisation with pollen coming from the same flower, or the same plant. Repeated self-pollination leads to homozygosity, and the formation of a pure lines. Note that cross-pollination within a clone (e.g., potatoes) is equivalent to self-pollination.

**Sterile males**

An entomological technique for controlling certain insect pests. Large numbers of male insects are made sterile, usually by radioactive irradiation, and are then released. They mate with females which then lay infertile eggs. The technique works best with species in which the males mate many times but the females mate only once.

**Synthetic variety**

An improved variety of an outbreeding species, such as maize, sorghum, or alfalfa, which is a genetically diverse population.

**Value for cultivation and use (VCU)**

A test of merit for a plant variety to determine differences of productivity, quality, pest and disease resistance and/or other commercially important qualities to qualify for marketing.

**Variety denomination**

The name of a new variety. Seeds and propagating materials are to be sold under the proper variety name, and labelled by variety and producer. The breeder owns the registered variety name.

**Variety maintainer**

The maintainer of a variety is a person or an organisation responsible for maintaining the variety and ensuring that it remains true to type throughout its full life-span and in the case of hybrid varieties that the formula for hybridisation is followed. Maintenance may be shared. Note: For listing purposes, the maintainer can be the national office of the company responsible for the variety even when the maintenance process for the variety takes place at another location.

# ANNEX 2: PLACE OF PARTICIPATORY RESEARCHES, DIVERSITY MANAGEMENT AND NEW CONCEPTS OF PLANT BREEDING TO COPE WITH CLIMATE AND AGRICULTURAL CHANGES

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## Introduction

Vernooy (2003) broadly defined Participatory Plant Breeding (PPB) by approaches that involve close collaboration between researchers and farmers, and potentially other stakeholders, to bring about genetic improvements within crops. In the conditions where it is mostly applied, participatory plant breeding (PPB) is an organization of the plant breeding process which aims to answer several questions at the same time: (1) at the production level, the needs of specific varieties associated to the absence of adapted varieties on the market and no interest for seed companies, (2) at the ecological level, the means to develop cultivated biodiversity for more sustainable agroecosystems, (3) at socio-economical level, the wish of some groups of farmers to get more empowerment and to become self-sufficient for their seed input. Participatory approaches emerged in the 1990s in the south countries to better fit the needs of the marginal areas where the varieties bred for the Green Revolution couldn't be cultivated. It has been described by several/a lot of authors (Almekinders and Elings, 2001; Ceccarelli et al, 2000, 2003; Machado and Fernandes, 2001; Sperling et al. 2001; Vernooy, 2003; Weltzien et al, 2008; Witcombe et al, 2001).

In the developing countries, Salvatore Ceccarelli and Stefania Grando (2007) summarize the situation:

> "It is widely recognized that conventional plant breeding has been more beneficial to farmers in high-potential environments or those who can profitably modify their environment to suit new cultivars, than to the poorest farmers who cannot afford to modify their environment through the application of additional inputs and cannot risk the replacement of their traditional, well known and reliable varieties. "

In Europe and other developed countries, PBB was the best answer to answer the needs of organic agricultures and all forms of low input agricultures. The basic hypotheses of plant breeding are: (1) crops are best adapted if the plants are selected in the conditions for which they will be exploited and (2) inter and intra-varietal diversities are the best way to increase the sustainability of the agroecosystems.

## Main breeding needs for the EU bioeconomy 2020 and climate change that are not covered or that are currently covered insufficiently by conventional breeding sector

What does climate change mean? What does it point out from an agricultural point of view ? Climate change reminds us of getting aware of the necessity of continuous adaptation of the livings beings. Homogeneity and stability don't belong to the living sphere and eco-system postulates.

> "In general, evolutionary systems do not relate to stability in a static sense as they are faced with moving equilibria and the dynamics of co-evolutionary interactions which cannot be foreseen *ex ante*. The process of adaptation is a permanent process of unpredictable change. If optimality exists it will be temporary, because through evolution, selection and innovation, and environmental change, including co-evolution, it is easily transformed into maladaptive traits. Under such conditions, diversity is a key element of long term stability and even survival. This holds equally for biological and economic systems." (Rammel and van den Bergh, 2003).

Thus, the same author proposes that from an evolutionary point of view, diversity is related to the "co-evolutionary potential" as the capacity of systems (sub-systems or agents) to establish new evolutionary interactions which might initiate future development trajectories. Facing climate change, all biological processes are looking for new development trajectories, and have we evaluated our breeding methods and agronomical processes to better cope with this challenge in the agroecosystems?

> "However, the flexibility and adaptability of a farming system has seldom been the target of research on improving farming practices or designing technical innovations. Most of the developments have focused on increasing productivity, improving product quality, optimising production processes, reducing the environmental impact, minimising costs, or maximizing profits." (Darnhofer et al, 2010)

Historically, crops have been grown as populations (landraces), which has allowed the diversification of crop varieties, adaptation to contrasting environments and use and maintenance of genetic diversity. During the twentieth century, pure lines and F1 hybrid have become dominant in developed countries in a combination of intensification of agricultural practices and intellectual property regimes. But the limitation of adaptability of those types of varieties was hidden by inputs the natural environmental impacts. The lack of diversity induces a rapid turn-over of the varieties (Dawson and Goldringer, 2012). Most of the modern varieties are genetically similar and rely on narrow genetic backgrounds, and then breeding programmes are vulnerable in unpredictable environmental changes (Finckh, 2008). Finckh et al (2000) and Finckh (2008) reviewed relevant information of the use of genetic diversity for disease control. Half century ago, scientists proposed to introduce diversity and adaptation process in plant breeding but they were not understood. The basic idea was that subsequent generations of cropping in bulk under natural selection of a hybrid population would lead to an improvement in agricultural fitness where environmental interactions are both biotic and abiotic (Suneson, 1956). It was described as a "new" method of plant breeding (Phillips and Wolfe, 2005). He only suggested that it is important to recognize the value of evolutionary fitness in plant breeding. This new method has regained a new development with Composite Cross Populations investigated by several teams in Europe (Wolfe et al, 2008) and the creation of new populations (Osman and Chable, 2009). Experimentally for wheat, Goldringer and her team showed that populations significantly evolved, after their cultivation in different sites during 10 generations, maintaining a broad level of diversity on "neutral" markers and moreover multiple alleles at candidate gene loci, including alleles not found in parental varieties (Dawson and Goldringer, 2012).

Nowadays, PPB for organic and low inputs agriculture is increasing to maintain and to create new landraces. The programmes are mainly sustained by public plant breeding sector.

> "As explored in the previous sections, using species or varietal mixtures for pest and disease management and enhanced pollination services, as well as for ensuring the agroecosystem against abiotic stresses, can also increase productivity and long-term stability of the system. Although it may not yet be entirely apparent that genetic diversity is important for present-day delivery of valuable ecosystem services from our agricultural ecosystems, the conservation of this diversity stabilizes ecosystem functioning in the long-run, and thus ensures delivery of ecosystem services in the future." (Hajjar at al, 2008)

### The recent evolution of the public plant breeding sector in the EU to answer to this needs: the PPB challenges and organisation;

> **"PPB in particular, is defined as a form of plant breeding in which farmers, as well as other partners, such as extension staff, seed producers, traders, NGOs, etc., participate in the development of a new variety. The objective is to produce varieties, which are adapted not only to the physical but also to the socio-economic environment in which they are utilized." (Ceccarelli and Grando, 2007)**

In the 1990s, PPB projects had been initiated in developing countries by international research institutes to improve the adoption of new varieties and to better take into account marginal areas. In a recent review, Desclaux et al (2012) described the conditions of the emergence of PPB in Europe and North American countries, as both socio-political and scientific projects, mostly by farmers involved in associations promoting sustainable agriculture and researchers preoccupied with biodiversity preservation. The PPB has been organized to solve many kinds of

problems: the erosion of local genetic resources, the lack of formal breeding programmes, the lack of competition among breeding programmes, the low efficacy or efficiency of breeding programmes, lack or ineffectiveness of seed systems. Organic agriculture and production in marginal areas share several of these failures of the formal seed system and/or breeding researches due to:
- the heterogeneous environments which cannot be standardized by input supply,
- the broad diversity of farmers' needs,
- the lack of varieties adapted to the various environments and practices (Desclaux et al, 2012).

For organic agriculture, the organisation of PPB reinforces the attachment to the four major principles of organic agriculture (Health, Ecology, Fairness and Care) through: (i) the use of breeding processes that respect the biological characteristics and the integrity of the species (Lammerts and Struik, 2004 and 2005), (ii) the enhancement of local adaptation which sustains the ecological system, (iii) the promotion of a small-scale seed market where trust between operators must be the first rule, and iv) participatory research for healthy seed production and adapted crops and the development of cultivated diversity for future generations (Döring et al, 2012).

A special mention must be done about breeding methods which established a gap between conventional breeding in the seed companies and the conception of plant breeding for Organic agriculture. ECO-PB (European Consortium for Organic Plant Breeding) in Europe and IFOAM (International Federation of Organic Agricultural Movements) relay the organic position about the breeding methods and maintain firmly the attachments the naturalness of the breeding processes.

There are several kinds of PPB organizations in the world which cover all the situations between a "scientific plant breeding model" and a "traditional farmer breeding". They are described in the following scheme[48]. The first form is historically "participatory varietal selection" (PVS) and this form is still often the first step of the establishment of a common experience between researchers and farmers.

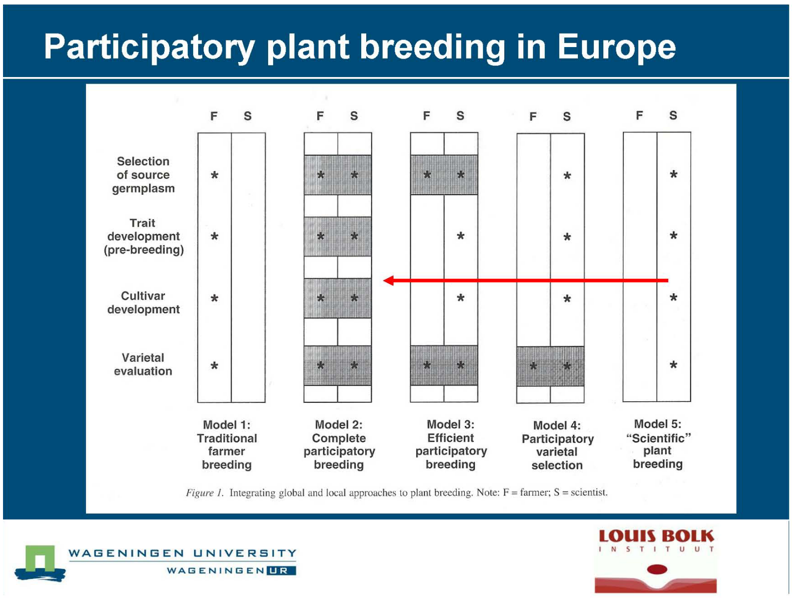

*Figure 1.* Integrating global and local approaches to plant breeding. Note: F = farmer; S = scientist.

48 http://cd.planetdiversity.org/fileadmin/files/planet_diversity/Programme/Plenary_Session/14_05/Lammerts_14_5_Europe_Organic_ppt_en.pdf

The starter in Europe was EU Regulation 1452/2003 which required the use of organic seed for organic agriculture and which went into force in 2004. At this moment, organic seed professionals were not ready to fulfill the demand. Seed companies consider the organic market too small to justify specific programmes. Breeders gave priority only to the storage and bulb quality traits but organic farmers also need varieties that perform well in the field. Breeders give low priority to field selection, e.g. to make mechanical weed control easier, farmers prefer plants with a more erect growth habit. Moreover, the cytoplasmic male sterility system used to produce these hybrids does not comply with organic principles (Osman et al, 2008).

Thus, organic farmers started to meet with researchers and to build the first PPB projects. For instance, in Germany, knowing that organic farming requires cultivars that are specifically adapted to this low input cropping system, organic farmers and scientists joined in a participatory breeding approach to develop region-specific genotypes of spring faba bean for organic conditions (Ghaouti et al. 2008). In the Netherlands, PPB was also the most efficient strategy to address the needs of organic onion producers because commercial onion breeders select varieties solely for conventional farming (Lammerts van Bueren et al 2005). In Portugal, PPB was initiated with two objectives not specifically linked to OA: the conservation of the white maize populations for the traditional bread and the maintenance of evolutionary processes in the farmers' fields, which could be valuable for continuing adaptation to future environmental conditions (Patto et al, 2008). In France, PPB began in 2001 in three areas in France: (1) In Brittany (the western part of France) a regional organic umbrella (IBB, Inter Bio Bretagne), and researchers from the national institute for agricultural research (INRA) have initiated a participatory plant breeding programme for organic cabbages and cauliflowers (Chable et al 2008). The aim was to include all concerned actors (farmers, processors, traders, trainers, researchers…) in defining the objectives and the means to reach them; (2) In the Mediterranean region in southern France, organic farmers needed varieties of Durum wheat, with the aim to produce grain with sufficient protein content and vitreousness for the pasta process (Desclaux, 2005). The pasta makers were involved in the project; (3) Maize and sunflower farmers in south western France had several objectives for breeding, including quality, rusticity and adaptation to dry conditions. The project was led by a local farmers' organisation (AgroBio Périgord), and locally funded by the region, with research support from an independent breeder. Farmers and the breeder have worked in parallel from the same populations to evaluate two breeding strategies for organic agriculture: PPB on farm and the creation of composite varieties for farmers who were not ready to breed their own varieties (Chable et al, in preparation).

At the end of September (2012), the Périgord region, where maize PPB begun, will welcome PBB actors from all France and several countries from all the continents, included Brazil where Altaïr Machado initiated maize PPB (Machado and Fernandez, 2001). He will come there to share experiences with the French farmers.

From a scientific point of view, the varieties bred on farm invite the researchers to renew their genetic approaches. We are no more considering individual plants or genotype, but plant populations (Wolfe, 2000; Thomas, 2012). The rapid evolution of these plant populations deals with genetic and epigenetic mechanisms controlling plant plasticity in response to environmental stimuli. Statistical and/or quantitative population genetics methods, combined with epigenetics approaches will be developed to apply to these breeding populations submitted to the various selection pressures or stimuli (e.g. agro-climatic conditions, crop management systems and selection practices). Indeed, the subject is quite exciting for a researcher, in public institution, which aims to enlarge and enrich his scientific concepts and methods.

> "Understanding the ability of farms to be adaptive raises the challenge to identify and develop methods to capture the dynamics of a system, and analyse which characteristics strengthen or threaten the ability of farms to adapt. Participatory methods are a promising avenue, as most disciplinary scientific models cannot capture the complexity of relationships or their dynamics, whereas farmers juggle them on a daily basis. Thus, researchers face the dual challenge of developing adequate theories and methods to understand the dynamics of co-evolution, as well as ensuring that their recommendations are relevant to real-world decision-making. Learning to live with change and uncertainty requires a fundamental conceptual shift, from assuming that the world is in a steady state to recognising that unexpected change is the rule." (Darnhofer et al, 2010)

## The recent evolution of the official position about thinking agriculture to answer to the challenge of the climate evolution and the environment perturbations;

> "A few decades ago, agronomists were faced with a sharp increase in pest outbreaks in modern monocultures, while ecologists were starting to model the complex interactions between insects and plants. At the same time, scientists were observing the effectiveness of traditional farming systems. The two scientific disciplines of agronomy and ecology converged, shaping the field of agroecology. Agroecology is the application of ecological science to the study, design, and management of sustainable agriculture. It seeks to mimic natural ecological processes, and it emphasizes the importance of improving the entire agricultural system, not just the plant. " De Schutter (2011)

The reliability and relevance of the principles of agroecology are more and more recognized. The scientific paradigm on which agroecological engineering relies is ecology. The objective is to design productive agricultural systems that require as few agrochemicals and energy inputs as possible, and instead relies on ecological interactions and synergisms between biological components to produce the mechanisms that will enable the systems to boost their own soil fertility, productivity and crop protection (Altieri, 1995).

Then, the scientific approaches would progressively evolve. While the objective of genetic engineering is to improve only a single element of the agroecosystem (modifying existing plants or designing new plants), the objective of agroecological engineering is to improve the structure of the agricultural system and "to make every part of the structure work well" (Liang,1998). It was the principle of the pioneers of organic agriculture during the first half of the 20$^{th}$ century.

Some agronomists and scientists are nowadays aware of the fact that nature might provide a model for a more sustainable agriculture. One of them, Michel Griffon, an agronomist and economist, who leads the French National Agency for Research (Agence Nationale de la Recherche, ANR in French), recognized that European public research has neglected several areas of knowledge. "*In 2008, the ANR funded a research programme called Systerra, which includes several projects of "bio-mimetic inspiration".* Today, the introduction of some values of agroecology has given birth to a new concept of "ecologically intensive agriculture", concept which combines conventional agriculture and some ecological approaches.[49] In his reflection, the most important is the crucial question about the nature of the plant populations needed for the maintaining of the environments' quality.

> Michel Griffon recently declared : « A mon avis, l'avenir de la génétique végétale ne se trouve pas dans la création de variétés hyper spécialisées, mais plutôt de variétés qui s'adaptent à de multiples situations. Nous n'avons plus besoin de "formule 1", mais plutôt de voitures "résilientes", capable de faire beaucoup de choses différentes. C'est pourquoi la recherche travaille aujourd'hui sur des variétés dites "population", des variétés complexes, issues de la diversité génétique et capable de s'adapter rapidement aux modifications de son environnement. ».[50]

Is this recent position a chance for PBB programmes with farmers to be promoted in our public institutions in Europe? Who will breed the "population varieties", except farmers with researchers from public institutions who are not obliged to be directly rewarded through royalties?

> "Clearly, breeders must be rewarded for their work and one way is through royalties. However, the current legal situation in all member countries of the Union for the Protection of New Varieties (UPOV) prevents the inclusion of functional genetic diversity for disease, pest, and other abiotic stress resistances into population varieties. In

[49] http://www.ellenmacarthurfoundation.org/explore-more/think-differently/an-ecological-future-for-agriculture.pdf

[50] Extrait d'une conférence donnée par Vivea, le fond en charge de coordonner la formation aux agriculteurs. En avril 2012

> addition, it does not allow for the deliberate production of population varieties where pure lines are the standard. There is a need to find new solutions that will allow breeders to be compensated for their efforts without constraining the potential for improving yield stability and the durability of disease and pest resistance in practical agriculture through intra-crop diversity." (Finckh 2008)

Seed regulations were already questioned during a European programme, Farm Seed Opportunities (2007-2010), in order to cope with all the seed systems still existing in Europe. One question was the place of "conservation varieties" for which the policy makers have postulated that they may fit better to niche agriculture, and no place previously existed for them in the European seed laws. Another was about the specific needs of organic sectors. Then, the consortium developed propositions for farm seeds, from landraces maintained to new populations bred by the farmers in the frame of PBB activities.

## The potentials and constraints of the public breeding sector to address these needs;

### *The scientific development*

PPB associating farmers and researchers from public institutions is an opportunity for knowledge evolution and methodology approaches. Plant breeding has to integrate interactions with ecological, agronomical and socio-economic domains. Researchers have to manage analytical approaches in a multidisciplinary context with systemic approaches: thus "a global approach". Some authors declared that "researchers are increasingly calling for a new dynamic paradigm; such a new paradigm is meant to, firstly, help understand how these systems interact across different scales, and secondly, how to manage them" (Rammel et al 2007).

> "The role of agrobiodiversity in adaptation to climate change must be better understood and recognized. Areas of competence include, among others: Biophysical and socioeconomic drivers and change in major components of agrobiodiversity including crops, wild crop relatives, trees, animals, fish, microbes; In situ and ex situ conservation and on-farm management of agrobiodiversity; Breeding for resistance to abiotic and biotic stresses; Enhancing links between genebanks, breeders and farmers; Policy implementation, and the role of local knowledge. Agriculture extension will need to work with farmers on the substitution of species and varieties adapted to the emerging climate." (Rammel et al 2007)

Researchers have a great opportunity to develop a new scientific culture based on "diversity". The context of the last century was to simplify the studied systems in order to better manage them with industrial purposes. Its scientific approaches during the 20$^{th}$ century were organized in the framework of the "paradigme fixiste", i.e. a paradigm where the livings organisms has been fixed as material objects. (Bonneuil and Thomas, 2007).

Now, from the point of view of the organization of the research, public institutions like INRA in France have not still measured the potential of this kind of research. Most of the researchers, now involved in the participatory processes are isolated with little help inside their institution. The European projects is the only framework where few researchers involved in PPB with the farmers may develop their new scientific paradigm. The organization of the public institution has favoured the enlargement of existing teams, reducing the chance of development of individual initiatives and the renewing of scientific themes as all novelties have to be agreed at all the levels of scientific decision before to be prioritized in matter of staff investment.

In agriculture, participatory research has been initiated for the development of systems close to the principles of agroecology. Many scientists do not explore these agroecological innovations because "it goes against the flow" (Valanquoren and Baret, 2009) and are not favourable to publications: PPB and agroecology need time.

Time and size requirements for research on each paradigm *(i.e. technonogical paradigm and agroecology paradigm)* also differ widely. The transposition of a transgene into a host plant can be detected by easy means in the lab within days, and lead to scientific discoveries that are published in renowned scientific journals. In contrast, sound research on a number of agroecological subtrajectories requires large-scale and long-term on-farm experiments… Scientists in academic institutions aim to improve scientific knowledge and share discoveries through publications, which are non-market incentives to value priority in scientific discovery. Yet the different technological paradigms lead to dissimilar publication trends and impacts. The difference of academic prestige between the two technological paradigms may be grasped by a simple bibliometric analysis of some of the most appraised scientific journals: genetic engineering features roughly a hundred times more than agroecological engineering in Nature, Science and The Proceedings of the National Academy of Sciences. In general, research representative of genetic engineering is published in scientific journals with impact factors (IF) as high as 29.3, while agroecological research is published in journals with IF ranging from 0.4 to 4.5. (Valanquoren and Baret, 2009)

Un entretien Bruno Chaudret (Journal L'Humanité, 24 février 2012, p16) : «La recherche ou, la quête désintéressée du savoir». Il est Directeur de recherche, Président du Conseil scientifique du CNRS (Centre National de la Recherche Scientifique), il analyse les changements rapides et profonds imposés aux fondements même de la recherche publique, mis à mal par les politiques libérales. Il donne son point de vue sur les rapports entre le chercheur et le citoyen. Une question à Bruno Chaudret : « Le temps, donner du temps à la recherche, semble pour vous une donnée fondamentale? » Sa réponse : « Pour être créatif, il faut du temps. La compétition ne renforce pas la créativité, elle peut réduire le temps entre la recherche et l'application. On va certes plus vite mais, à mon avis, au détriment de la créativité. »

## 4.2 Public support

At the European level, interdisciplinary and multidisciplinary approaches, often associated to participatory organizations of the research, are involved in SOLIBAM, an FP7 project funded by the European Commission. At the beginning, our problematic was based on the fact that low-input and organic farming systems require crop genotypes that are specifically adapted to their typically higher environmental variability and that modern bred genotypes are often unsuited under these conditions. The EU Regulation 1452/2003 in force, the organic sector was not only striving for organically produced seeds from conventional varieties, but was also urging for breeding and management strategies for better adapted varieties. This became more urgent in a time of climate destabilisation. **The potential of genetic diversity at the crop level** for stabilizing low input farming systems and for enabling adaptation to environmental changes is now recognized theoretically and is the basic hypothesis of SOLIBA which aims to exploit it in practice during its duration of 4.5 years with 23 organisations in Europe and Africa. SOLIBAM is developing participatory plant breeding approaches to answer to key adaptation bottlenecks of organic and low-input agriculture. Farmers, users and researchers are full partners in the development of new methodologies and technological innovations, with full decision-making power in planning, implementation, monitoring, and evaluation. We are associating plant breeding and crop management (PPBM) in several agroecological conditions to best adapt genotypes to environments. ICARDA, which initiated PPB in Syria 20 years ago, will share its experience with European and African ones.

The advantage of European research is to connect competences/experiences which are isolated in their countries or institutions. Another aspect is the re-enforcement of public engagement in research when private organizations are involved in the projects. It gives also opportunities to demonstrate the interest of **new research topics which are not always considered in national institutions**.

## The informal seed systems

### *The development of the farmers' networks*

Besides the scientific challenges, farmers who are involved in PPB actions are really motivated by both the breeding activity itself and by the potential gain (from agronomical, economical, social and market points of view) represented by the improved varieties and the "free" seed. Even if breeding and seed production mean for them an extra quantity of work, most of them have succeeded in introducing breeding and seed multiplication within their production schedule. The rapidity of adaptation of the plant populations has often surprised them: i.e. precocity and morphological evolution (Serpolay, 2011b, Dawson, 2012a, Dawson, 2012b) have given them confidence. All the groups or associations agree that the next step is the creation of "seed community banks" (Chable et al, 2011) where the conservation could be collectively organised, where collective material and machines could be found to thresh and clean the seed, to measure the seed quality and where know how could be exchanged. The question is now how to find means for these houses, and the involvement of members from the society (consumers) is very important to help farmers to support the safeguard of the diversity and the creation of locally adapted varieties.

Nevertheless, the quantification of the investment of the farmers is only possible indirectly because most of the farmers want to remain discrete because they are anxious about the non adaptation of seed laws. **They don't want to be known by the official bodies: they constitute "an informal seed system"**. The indirect way of measuring the evolution of the farm breeding of peasant varieties is through **the increasing of the number and size of collective organisations**. In France, the first people involved in the safeguard of cultivated biodiversity and on farm breeding, mainly using organic practices, met for the first time in Auzeville in 2003: national organic organisations and several agricultural trade unions (la Federation Nationale de l'Agriculture Biologique, la Confédération Paysanne, Nature&Progrès, la Fédération Nationale d'Agriculture Biologique des Régions de France, le Mouvement de Culture Bio-Dynamique, Bio d'Aquitaine, le Groupement de Développement de l'Agriculture Biologique Midi-Pyrénées, le Syndicat des Semences et Plants bios du Languedoc-Roussillon). There, they met other farmers involved in similar initiatives and shared their first experiences with researchers who had initiated PPB actions or were involved in the management of genetic resources and small-scale breeding companies. This event consolidated the farmers' determination to take charge of the future of their varieties and seeds. The farmers also considered the starting point for a new form of collaboration between researchers and farmers in France. The association "Réseau Semences Paysannes" (peasant seed network), was born after this meeting and brings together several local networks, insuring a link between farmers and authorities to stimulate the necessary adaptation of French registration laws. In Spain, La Red de Semillas "Resembrando e Intercambiando" (www.redsemillas.info/) represent a group of a several stakeholders involved in biodiversity safeguard. They have been working since 1999, but became an official organisation in 2005. La Rete Semi Rurali (www.semirurali.net), in Italy, was officially born in 2007 from an informal group of researchers and farmers working together from 2000 (Bocci and Chable, 2008).

Nearly 10 years later, in France, the administrative board of RSP is counting **65 seed/biodiversity associations** in its network and RSP is considering, next month, the application forms of 4 more associations dealing with on-farm breeding in France. The creation and the rapid development of seed/biodiversity associations in France represent the development of on farm breeding in the country. We may consider that each association counts at least 20 members at its beginning and some of them have now several hundred members.

At the end of September 2012, RSP organises "Les Rencontres Internationales des Maisons des Semences Paysannes" where French and international organizations (representing all continents) are expected to share their experiences in matter of on farm breeding and community seed banks. This event will be followed by a broad event, open to all public, La Fête des Maisons des Semences Paysannes.

## ***The European support and organisation***

At the European level, we have also to notice the creation in 2012 of the European Coordination for farmers'seed, which constitutes a network of the different national networks. The current members are: Réseau Semences Paysannes (France), Rete Semi Rurali (Italy), Red de Semillas (Spain), Pro Species Rara (Switzerland), Arche Noah (Austria), Scottish Crofting Federation (UK). The creation of the European coordination was helped by an European project: Farmer's Seeds Project - Best Practices in Sustainable Agriculture and Food Sovereignty[51] (funded by the UE commission for 36 months, 1.300 KEuros with Italy, France, Scotland, Romania, Hungary, Senegal and Tunisia, 2009-2011).

This project itself was born through the action of an informal network, the "Let's Liberate Diversity", which organizes each year a forum gathering of farmers and associations from all across Europe. The first one was organized by the RSP in Poitiers in 2005. The last one was in March 2012 in Scotland and hosted by the Scottish Crofting Federation. The year before, in Szeged (Hungary) at the plenary session on February 26, 20011, the DECLARATION OF SZEGED was adopted. This declaration highlights the contributions of farmers to the development and renewal of agricultural biodiversity in Europe and calls on national governments, the European Union and Contracting Parties at the 4th Governing Body meeting of the International Treaty on Plant Genetic Resources for Food and Agriculture, held in Bali in 2011, Indonesia to make concrete progress in the implementation of Farmers' Rights and the Sustainable Use of PGRFA. The political foundations of the European network will support the common position on the reform of EU legislation on seeds by several national networks in Europe.

## **Conclusions**

> "Biodiversity is essential for food security and nutrition and offers key options for sustainable livelihoods. Food and nutritional security can be enhanced by making better use of a plant, tree and animal diversity, **through participatory breeding of local varieties, or a commercialization of neglected and underutilized crops**.(Rudebjer et al, 2009).

Research dealing with plant breeding had been organized to answer to the industrialization of agriculture. Applied research in biology, chemistry and genetics has influenced agricultural systems. Now, a radical change has been called from many actors of the society. This call had been relayed by International Assessment of Agricultural Science and Technology for Development in 2008: after a 4-year process that involved over 400 international experts, it has been recommended a reorientation of agricultural science and technology towards more holistic approaches (IAASTD, 2008). These approaches are in the heart of the PPB and agroecology sciences. These research themes would stimulate an true "public organization" in which researchers, with public funds, may contribute with many actors of the society, and may offer new models of development of agriculture and plant breeding.

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[51] (http://www.farmerseeds.org/ ) 'Farmer's Seeds - Best Practices in sustainable Agriculture and Food Sovereignty: development of an inclusive approach in the Fight against Poverty' - DCI NSA ED/2009/201-955; NSA: Non-state actors and local authorities in development.

# ANNEX 3 : RESEARCH METHOD (IN DETAIL)

This chapter presents the details of the methodological tasks that have been applied during the course of the research study to delivery of the project and achievement of its objectives. The twelve months project started at the beginning of 2012 with a kick-off meeting that took place on the 4 January 2012 in Sevilla.

The overall project workflow is shown in the following table.

**Project plan of the study**

| Task No | Task description | Due month |
|---|---|---|
| **1** | **Breeding needs for the EU bio economy and climate change** | **4** |
| 1A | Review of main breeding needs for the EU bio economy | |
| *1A.1* | *Literature review* | |
| *1A.2* | *Interviews and survey with researchers, and other stakeholders* | |
| 1B | Identification of breeding needs insufficiently covered by the private sector | |
| *1B.1* | *Review and completion of data sets gathered under task 1A* | |
| *1B.2* | *Review of the preliminary results with variety registration and variety protection bodies* | |
| *1B.3* | *One-day workshop with research and private plant breeding community* | |
| **2** | **Potential and constraints of the public breeding sector (or public/private partnerships) to address breeding needs for the EU bio economy and climate change** | **8** |
| 2A | Mapping the development of the public plant breeding sector | |
| *2A.1* | *Analysis on the evolution of the public plant breeding sector since 1950 in the EU 27 MS* | |
| *2A.2* | *Analysis of the complementary developments in the private sector* | |
| *2A.3* | *Analysis of the evolution of the breeding EU sector in comparison to the global situation* | |
| *2A.4* | *Analysis of the evolution of training and capacity building in plant breeding* | |
| 2B | Mapping the current status, capacity and potential of the public plant breeding sector (including private/public co-operations) | |
| *2B.1* | *Listing of public plant breeding actors in the EU 27 MS based on the analysis of the national and European catalogues* | |
| *2B.2* | *Development of a survey to quantify current status, capacity and potential of the public plant breeding sector* | |
| *2B.3* | *Launching and follow-up of the survey* | |
| *2B.4* | *Review of the outputs concerning the release of varieties by institute* | |
| **3** | **Synthesis report** | **9** |

## Task 1A.1: The literature review

The literature review aimed at identifying the main publications (including monographs, reviews, scientific papers, and grey literature) which discuss the plant breeding needs for the EU bio-based economy and climate change.

This included the relevant academic literature as well as other reports, position papers and other secondary sources produced by the Commission, national governments, and a variety of stakeholders, including representative organisations at international, EU and national levels. All publications related to the breeding needs have been compiled in an EndNote database.

A significant number of the publications listed in The EndNote library have been collected via the network of experts that the research team has consulted during the study (this task has been initiated and performed in parallel with Task 1A.2: (interviews with experts)  and not from scientific electronic databases.

Eventually, very few publications are presenting breeding needs at crop/trait combination level; rather they indicate needs for the global cropping system.  Plant breeding approaches are considered at global level for several major crops (maize, soybean, vegetables) and therefore this literature review is not limited to the situation in the EU but is considering the international context of these R&D activities.

### Scientific databases search

Literature search has been carried out in the major scientific electronic databases and online libraries as follows:

- Biological abstracts (BIOSIS Previews)
- Web of science (Science Citation Index)
- CAB Abstracts (agriculture citations)- International in scope. Plant breeding, horticulture, and grasslands are among its subjects. Includes the data from the TREECD (Forest Science Database).
- Agricola (U.S. agriculture literature citations)
- Scopus (all science fields) - Includes links to citing articles
- Online Journals
- Find Articles *(multiple databases)*
- Borrow Direct
- Interlibrary Loan
- Science Online Databases
- **http://www.mdpi.com**

In addition, several additional and dedicated websites have been screened:

- The European Plant Science Organisation  (EPSO) **http://www.epsoweb.eu/catalog/tp/**
- A European Genebank Integrated System (AEGIS): **http://aegis.cgiar.org/**
- EURISCO web-based catalogue that provides information about ex situ plant collection: **http://eurisco.ecpgr.org/**

- General information on bio-economy: **http://ec.europa.eu/research/bioeconomy/**
- International Center for Agricultural Research in the Dry Areas (ICARDA): **http://www.icarda.cgiar.org/Facelift.htm**
- European Cooperative Programme for Plant Genetic Resources (ECPGR): **http://www.ecpgr.cgiar.org/**
- International Community of Asexually Reproduced Ornamental and Fruit Plants (CIOPORA) **http://www.ciopora.org/service/press.html#.T316T_B6-So**
- International organisation OECD : **Http://www.oecd.org/department/0,3355,fr_2649_36831301_1_1_1_1_1,00.html**
- Publications about bio-refinery: **http://www.biorefinery.nl/publications/**
- Information on breeding developments and public-private partnerships: **Http://www.upov.int/meetings/en/topic.jsp?group_id=73**
- Permanent International Committee for agricultural research: **http://www.iddri.org/Publications/Publications-scientifiques-et-autres/Sustainable-food-consumption-and-production-in-a-resource-constrained-world**
- CIRAD website
- Seedquest website (industry website)

Researchers met or contacted during the study have been invited to provide references and publications addressing plant breeding needs.

The list of the main keywords being used during the electronic search is as follows:

- Agriculture needs
- Agriculture innovation and breeding
- Biobased economy
- Biodiversity
- Biorefinery
- Biomass
- Breeding needs
- Climate change and breeding
- Crop productivity
- Food safety
- Molecular breeding needs
- New breeding techniques
- Novel food and breeding
- Plant breeding evolution
- Plant breeding needs
- Plant breeding objectives
- Plant breeding techniques
- Plant health
- Raw material
- Sustainable agriculture and breeding.

## The interviews (in the context of Task 1A.1)

In addition to Task 1A.1, the research team has considered four major additional sources of information to complete this initial inventory of breeding needs:

- Researchers that are involved in pre-breeding activities and genomics ;
- National organisations (e.g. variety registration officers, variety protection offices, etc...)
- Plant breeding experts, and
- Agro-food supply chain actors. Plant breeding is an activity to serve an integrate supply chain and not only crop production. Therefore needs may come from downstream actors (food processors, industries producing biomaterials, etc...).

These interviews with researchers, plant breeding experts and agro-food supply chain actors have helped to complete the search done in the scientific library. In fact, the most relevant publications have been found via this direct approach (more in section 1A.2 below).

It should be highlighted here the rather poor interest of the agro-food supply chain actors (processors and downstream) in the subject matter. Plant breeding is an activity to serve an integrated supply chain and not only crop production (commodities). Therefore needs may come from the downstream actors (food processors, industries producing biomaterials, biomass for energy). When it seems that industries developing new product chains e.g. bio chemicals and bio energy seem to be interested by what plant breeders objectives are but on a case by case basis, the majority of food processors seem not to be fully concerned by plant breeding to the exception of productions that are based on an industrial approach (contracting with farmers).

The list of interviewees id presented under Task 1A.2.

## The EndNote database

All collected references are compiled in and EndNote database which is attached to the present report. The database is structured as follows:

**Structure of the EndNote database**

| Field | Description |
|---|---|
| Author (s) | |
| Year of publication | |
| Title | |
| Other authors | |

| | |
|---|---|
| Secondary Title | |
| Place Published | |
| Pages | |
| Type of support | |
| Type | Food/feed or Non Food biochemical or Non Food bio energy or All |
| Group of traits | |
| Crops | |
| Keywords | |
| Abstract | |
| Weblink | |

Three fields marked in red in the table above have been added in the Endnote library to help characterising the topic of each individual reference. It can be noticed that a large number of these publications is approaching the future breeding needs on a general level, and very few references are approaching the needs per crop, and even less per crop/trait combination.

## Task 1A.2: Interviews with researchers, plant breeding experts and agro-food supply chain actors.

Interviews with researchers, plant breeding experts and agro-food supply chain actors have been conducted during the first phase of the study (Task 1) in order to complete the literature search on the breeding needs for the bio based economy 2020 and climate change.

This first round of interviews was initiated at the beginning of February 2012, in total 55 interviews have been carried out by the team experts during February and March. The total list is presented on the next table. When selecting the experts to be interviewed, the study team paid a special attention to secure that all sectors have been considered and that the geographic coverage was representative of the major plant breeding areas of the EU.

These semi-structured interviews have been carried out by the team members based on the following guideline in support to the discussion. This guideline has only to be seen as a document to support the discussion but flexibility was given to the interviewer to focus on centres of interest of interviewees.

**IPTS Study – Interview guidelines with experts**

*This guideline should be used in the context of Task 1A.2 which is for each team member to interview face-to-face or by phone 3 to 5 breeding experts (see list of targets).*

*The main objectives of this these interviews is to better understanding the breeding needs addressing the mid-term national strategies in term of crop production for food and non-food supply chains and respect of the environment (e.g. in the EU, the so-called bio based economy).*

*The following themes should be discussed with the interviewees:*

- *Literature addressing future breeding needs:*
    - *Are you aware of any literature addressing future breeding needs?*
    - *Who could us to complete the first set of information we have already collected? Please provide 3 to 5 key experts in this area.*
- *Are you aware of the current public breeding institutes in your country? Could you, please, provide a list of these? If you do not have that list, who could provide it?*
- *Are you aware of any research and publications related to the evolution of crop productivity during the last 20 years in the major agricultural crops? Please provide these documents if available?*
- *Are you aware of any reports that has analysed the evolution of public plant breeding efforts and capacity during the last 20 years? Is yes, please provide the document if available.*
- *Are you aware of any publications/reports that has analysed the evolution of the public/private partnership in plant breeding during the last 20-30 years ? how has the model evolved 1) with the introduction of molecular breeding ? 2) with the introduction of biotech ?*
- *Could you please provide the name of 3 experts that you consider should be contacted for the study ?*

*=========================================================================*

*The future breeding needs have been categorised in a draft document and can be summarised as follows:*

- *Food security:*
    - *Productivity: sustainable yield increase;*
    - *Yield increase via improved cultivars resistant to diseases and pests;*
    - *Yield increase via varieties improved for a better fertiliser nutrients uptake from the soil;*
    - *Yield stability under stress conditions (cold, salinity, acidity, drought);*
    - *Yield stability for sustainable crop production in the EU – grain commodities sovereignty (e.g. sustainable and reliable protein supply for the livestock sector to reduce the dependence of the EU on imported protein crops)*[52]*.*
- *Food safety:*
    - *Varieties with lower susceptibility for fungi producing mycotoxins;*
    - *Varieties with lower susceptibility for allergenicity.*
- *Food quality:*
    - *Improved product composition profile (healthier oils, increased cooking stability, higher levels of isoflavones leading to reduction of cancer; heart diseases, low glucosinolates, additional nutritional values, high vitamins contents, etc.);*

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[52] In 2007, the EU-27 E.U. soybeans import were 15.3 million tonnes in 2006-07 and estimated at 13.5 million tonnes for 2010-11 Most imports originated from Brazil and Argentina.

    - *Improved varieties for alternatives agricultures (e.g. organic farming);*
    - *Improved varieties for production of specialty food ingredients (e.g. lecithine).*
- *Human Health:*
    - *Pharmaceutical products production in plants (e.g. therapeuthic glycoprotein).*
- *Feed production:*
    - *Varieties leading to more efficient feed for better weight gain and (e.g. improved energy content in silage maize, maize phytase for animal feed);*
    - *Improved varieties for improved digestibility by livestock (to reduce methane and nitrous oxide emission).*
- *Non-food production (feedstocks yields):*
    - *Improved cultivars for novel feedstocks for energy production (1st and 2nd generation biofuels);*
    - *Improved cultivars for novel feedstocks for the production of biomaterials (bio-based plastics, bio-composites and new fibres), carbohydrate enhancements, and renewable raw material for bulk chemicals (e.g. biobased method for using maize to produce the polymer for use in clothing, carpet and automobiles interiors).*
- *Respect of the environment:*
    - *Improved cultivars for a better fertiliser nutrients uptake from the soil leading to a reduction of the usage of fertilisers (less leaching and reduction of agricultural inputs usage);*
    - *Varieties resistant to pest and diseases leading to reduction of the usage of pesticides.*
    - *Crop adaptation to climate change and mitigation of climate change:*
        - *Varieties with enhance drought tolerance leading to less irrigation on certain crops (e.g. maize);*
        - *Varieties resistant to salt allowing cropping on soils with high salinity (e.g. fruit production);*
        - *Improved cultivars with the ability for plants to survive increasing intensities of ultraviolet radiation, due to damage in the ozone layer, and to respond favourably to elevated atmospheric concentrations of carbon dioxide.*

*This structure is a preliminary one that will be further elaborated based on discussions with the experts. Before finalisation, it will be submitted to IPTS for validation.*

*This list of needs will be assessed against a list of criteria as follows:*

- *Best breeding technique(s) to deliver the trait;*
- *Which incentives for private breeders to develop these traits;*
- *What are the business opportunities, evaluation of the pipeline of private breeders ?*
- *Is the trait developed by using a GM technology?*
- *Estimated cost to deliver;*
- *Estimated private breeding efforts involved (low, medium or high);*

- *Timelines for first commercialisation.*

The consultation targeted a selected subset of stakeholders, national organisations and individual companies (see list of targets).

**Figure 1: Number of interviews per type of stakeholders**

| *Sector* | *Total* |
|---|---|
| Industry | 15 |
| Policy maker | 7 |
| Producers | 9 |
| Research | 17 |
| Variety protection | 2 |
| Variety registration | 5 |
| *Total* | *55* |

**List of interviews**

| MS | Contact name | Organisation | Sector |
|---|---|---|---|
| BE | Philippe BARET | Université Catholique de Louvain | Research |
| DE | Frank BEGEMAN | IBV | Research |
| DK | Thor Gunnar KOFOELD | Danish seed council and forage | Producers |
| ES | Jose Miguel MARTINEZ ZAPATER | Research professor in the Science Institute of vineyard *Instituto de Ciencias de la Vid y del Vino (ICVV)* | Research |
| ES | Antonio VILLAROEL LOPEZ | ANOVE | Industry |
| ES | Elena Saenz GARCIA BAQUERRO | ANOVE | Industry |
| ES | Pedro Miguel CHROME FUSTER | Head of the Spanish office of vegetable varieties and the phylogenetic resources unit | Variety registration |
| ES | Amia ORTIZ BARREDO | Head of the vegetal production and protection department At Neiker-Teknalia | Research |
| EU | Annette SCHNEEGANS | DG RESEARCH | Research |
| EU | Manuel GOMEZ BARBERO | EUROPABIO | Industry |
| EU | Marc DUPONCEL | DG AGRI | Policy maker |
| EU | Arnaud PETIT | COPA COGECA | Producers |
| EU | Garlich von ESSEN | European Seed Association | Industry |
| EU | Isabelle CLEMENT NISSOU | DG SANCO | Policy maker |
| EU | Carlos GODINHO | CPVO | Variety protection |
| EU | Edgar KRIEGER | CIOPORA | Industry |
| EU | Lucia ZITTI | COPA COGECA | Producers |
| EU | Olivier DIANA | DG AGRI | Policy maker |
| EU | René L'HER | DG AGRI | Policy maker |
| EU | Walter de BACKER | DG AGRI | Policy maker |

| MS | Contact name | Organisation | Sector |
|---|---|---|---|
| FR | Christian HUYGHE | INRA | Research |
| FR | François DESPREZ | French plant breeder - Desprez | Industry |
| FR | Guy KASTKER | Confédération paysanne | Producers |
| FR | Joel GUIARD | GEVES | Variety registration |
| FR | Maria MANZANARES DAULEUX | INRA | Research |
| FR | Patrick DE KOCHKO | Réseau Semences Paysannes | Producers |
| FR | Philippe GRACIEN | GNIS | Industry |
| FR | Stéphane LEMARIE | INRA | Research |
| FR | Valentin DUVAL | CIRAD | Research |
| HU | Zoltán BEDO | President of EUCARPIA | Research |
| HU | Csaba MARTON | President of the Hungarian Breeders Association | Research |
| HU | János PAUK | Cereal Research Institute, Szeged | Research |
| HU | Miklós FARI | EUCARPIA | Research |
| INT | Marcel BRUINS | ISF | Industry |
| INT | Orlando de PONTI | Member of executive committee of ISF | Industry |
| INT | Peter BUTTON | UPOV | Variety protection |
| IT | Fulvia CALVINO | COLDIRETTI | Policy maker |
| IT | Marco NARDI | ASSOSEMENTI (Association of Seed Companies) | Industry |
| IT | Paolo ANNICHIARICCO | Centro di ricerca per le produzioni foraggere e lattiero-casearie (Lodi) | Industry |
| IT | Pier Giacommo BIANCHI | National Institute for Research on Food and Nutrition (INRAN-ENSE) | Variety registration |
| IT | Giovanni LAFFI | CONASE – Consorzio Nationale Sementi | Industry |
| IT | Stefano BISOFFI | International poplar commission of FAO | Research |
| NL | Chris ETTEKOVEN | NAKTUINBOUW | Variety registration |
| NL | David KASSE | Product board for agriculture | Producers |
| NL | Ernst VAN DE ENDE | Plant Science Group - Wageningen University and research | Research |
| NL | Marien VALSTAR | Ministry Ag NL | Policy maker |
| NL | Matte ELEMA | Product board for agriculture | Producers |
| NL | Mr SMITS | Product board for horticulture | Producers |
| NL | Mrs VAN DE KAMP | Product board for horticulture | Producers |
| NL | Niels LOUWARS | PLANTUM | Industry |
| NL | Richer VISSER | PRI-Wageningen University | Research |
| NL | Stephan VAN DER HEIJDEN | Barenbrug | Industry |
| NL | Thijs SIMONS | PLANTUM | Industry |
| RO | Teodor-Dan ENESCU | Testing Center for seed Romania | Variety registration |
| RS | János BERENYIi | President of Voivodina Academic Council, Agricultural Research Institute, Novi Sad | Research |

We have been facing a positive attitude from the persons that have been interviewed during this initial data collection. However it has to be noticed that very few of these experts have presented a global picture of the needs. Very often, their presentation was limited to a few traits without addressing the crops/traits combination. This may be considered as an indicator of what commercial breeders are breeding for today. The traits that have been mentioned the most often are yield and yield stability and, then, resistance to diseases and pests, resistance to drought, quality improvement leading to improved food (oil composition in oilseeds). Traits leading to e.g. cultivars improved for a better fertiliser nutrients uptake in the soil, for a lower susceptibility to fungi producing mycotoxins, or lower susceptibility for allergenicity have not been presented as key current objectives by breeders.

## Task 1B.1 Review and completion of data sets gathered under Task 1A.1.

The ToR of the study indicates that "*the contractor is required to map and evaluate (based on the results obtained in task 1A) which breeding needs are currently not or insufficiently covered by the private sector*". Plant breeding activities are covered by a high level of confidentiality. Breeders are not used to disclose their breeding objectives as these research efforts are not covered by any protection tools. To try to overcome this issue we have decided to strengthen our research team with individuals who have been involved in plant breeding in the major EU MS. These individuals are well known in their area and therefore we consider that, through them, we have been able to convince private breeders to share information.

These experts have also been selected to cover the majority of crops and group of crops with a correct EU geographic coverage. In more detail, the following table provides an overview of the team's skills and expertise according to the requirements in the ToR, as well as the role of the individual experts in the project and their category.

**Overview of core team's methodological knowledge**

| Team member | management | Data collection | Networking skills | Knowledge of breeding actors | Sectorial knowledge | Geographic coverage |
|---|---|---|---|---|---|---|
| L. Amat | X | X | X | X | Oilseeds, hybrid crops, biotech | All EU |
| A. Ayerdi | | X | X | X | Oilseeds, new breeding techniques | ES, FR |
| P. Caramangiu | | X | X | X | Oilseeds, maize | PL, RO, HU |
| V.Chable | | X | X | X | Participative breeding, all crops | All EU |
| A.van Elsen | | X | X | X | Vegetables, ornamentals, public/private partnership | NL, DE, BE |
| J. Gennatas | | X | X | X | PBR, variety protection | All EU |
| V. Negri | | X | X | X | Capacity building, trees breeding | IT |

| | | | | | | |
|---|---|---|---|---|---|---|
| F. Schmitz | | X | X | X | Agricultural crops, biotech, public/private partnership | DE, PL |
| D.Traon | X | X | X | X | Agricultural crops, industrial crops, biotech | All EU |

We would like to highlight that experts have been selected in order to cover the main breeding sectors in the main breeding areas in the EU 27 MS.

## Task 1B.2 Review of the preliminary results with variety registration and variety protection bodies

Task 1B.2 has helped to review the preliminary results with variety registration and variety protection bodies. For most of crops, variety registration and variety protection officials are key people at MS level as they have a complete overview of who is breeding (public and private) in their country and via the registration and protection processes they also know what is being researched. When a breeder applies for a candidate variety with a new trait or new characteristics, he has to mention it in its application form; and therefore officials are the first ones to be informed on innovations. In most of MS, this information regarding the submission of varieties with new traits is of public domain unless the applicant asks for confidentiality. This task has been started during Phase 1 of the study and continued during the Phase 2. Variety registration and variety protection bodies have only mentioned that a few applications have been received based on new traits other than the ones directly or indirectly linked to yield. Breeders are working on diseases resistance in order to guarantee an optimal yield level or quality level for propagating material (e.g. ornamentals); but very few examples exist to date on other traits.

## Task 1B.3 The workshop

A workshop has been organised on the 11 of April in Brussels with the main objectives of:

- Validating the preliminary results of the plant breeding needs; and
- Creating a network of public and private actors on which the Phase 2 of the study (and following actions) could be built on.

This event has been co-organised by Arcadia International with the strong support of the COPA-COGECA and the European Seed Association (ESA) via the European Technology Platform – Plants for the future. The ETP - Plants for the Future is a stakeholder forum for the plant sector, including plant genomics and biotechnology that was initiated by the European Commission in 2003. It provides a 20-year vision and a short-, medium- and long-term Strategic Research Agenda (SRA) for Europe’s plant sector setting out a consensus on the research needed to fulfil the vision. The SRA identifies five challenges for Europe’s society and economy to which the plant sector can contribute:

- Healthy, safe and sufficient food and feed
- Plant-based products – chemicals and energy

- Sustainable agriculture, forestry and landscape
- Vibrant and competitive basic research
- Consumer choice and governance

Its members come from industry, farmer organisations, academia and other stakeholder groups.

This platform has been considered as being the most appropriate to co-organise this event. Additionally, it has to be mentioned that the European Plant Science Organisation (EPSO is an independent academic organisation that represents more than 226 research institutes, departments and universities from 30 countries in Europe and beyond. EPSO's mission is to improve the impact and visibility of plant science in Europe) is member of this platform and therefore a direct link to more than 200 academic research organisation is created.

The conclusions of the workshop that are presented below have been distributed to all participants.

**List of participants**

### European Commission DGs and EU and national authorities

- JRC Institute for Prospective Technological Studies: Maria Lusser
- JRC: Guy van den Eede
- DG AGRI: Walter de Backer, Sébastien Crépieux, Marc Duponcel
- DG SANCO: Isabelle Clement Nissou, Matthias Less
- Ministerie van Economische Zaken, Landbouw en Innovatie: Dirk de Jong

### Public Research

- Agroscope Changins: Fabio Mascher
- INRA: Véronique Chable, Hélène Lucas
- Agricultural Research Institute of the Hungarian Academy of Sciences: Geza Kovacz
- Institut la Salle Beauvais: Alicia Ayerti Godor
- University Bologna: Roberto Tuberosa
- Athen University: George Skaracis
- Warwick University: Brian Thomas
- Wageningen University: Luisa Trindade, Andries Koops
- Rothamsted Research Institute: Andy Philips, Maurice Moloney
- Swedish University of Agricultural Sciences: Anders Nilsson

### Private Research

- Keygene: Marcel Prins
- KWS: Maria Midner
- Dow AgroSciences: Filip Cnudde

**EU & national associations**

- Plant ETP: Silvia Travella, Marc Cornelissen
- COPA-COGECA: Jean-Claude Guillon, Thor Kofoed, , Arnaud Delacourt, Dominique Dejonckere, Didier Sauvaire
- Fraunhofer IME: Stefan Schillberg
- ESA: Garlich von Essen, Jean-Paul Judson
- ANOVE:
- CIOPORA: Jan de Riek
- Plantum: This Simons, Aad van Elsen
- BDP-GDP : Jan Jacobi, Petra Gorash

**Background information & objectives of the workshop**

**The purpose of the workshop** is to identify what are the future plant breeding needs which are relevant for the bio-economy in the EU by 2020 and climate change. The workshop intends to evaluate which breeding needs are currently not or insufficiently covered by both private and public sectors.

**The event aims** to bring together the EU plant breeding community of the different sectors, farmers and experts from the food chain and non-food supply chain, as well as policy makers and responsible from the EU research funding schemes to exchange and agree on what are the future breeding needs by collecting feedbacks and opinions from the participants.

**Workshop programme**

Venue: COPA COGECA offices, Rue de Trèves 61, 1040 Bruxelles

| Time | Programme items | Speaker |
|---|---|---|
| 10.30 10.40 | Opening and Introduction | Daniel Traon - Arcadia International |
| 10.40 10.50 | Welcome speech | Arnaud Petit - Copa Cogeca |
| 10.50 - 11.10 | Objectives of the study | Maria Lusser - JRC-IPTS |
| 11.10 - 11.30 | Timelines and methodology of the study | Daniel Traon - Arcadia International |
| 11.30 - 11.50 | Presentation of the ETP – Plants for the future | Jean-Claude Guillon - Chair of Plant ETP |
| 11.50 - 12.45 | ***Working groups*** | |
| | WG1 - Food and feed | moderator: Roberto Tuberosa - Rapporteur: Maurice Molone |
| | WG2 - Non Food bio chemical | moderator: Andries Koops - Rapporteur: Stefan Schillberg |
| | WG3 - Non-Food bio energy | moderator Luisa Trindade - Rapporteur: Aad van Elsen |
| *12.45 - 14.00* | ***Lunch break networking*** | |
| 14.00 - 15.00 | Working groups (continued) | |
| 15.00 - 16.30 | Reporting on working groups by rapporteurs | |
| 16.30 - 16.45 | Conclusions and next steps | Daniel Traon - Arcadia International & Maria Lusser - JRC-IPTS |

**Results and outcomes of the workshop**

**Outcomes of the plenary session**

The workshop started with several presentations aiming at setting up the scene and at presenting the main objectives of the study. Dominique Dejonckeere welcomed the participants of the workshop at COPA COGECA and stressed the importance of the plant breeding and seed sector for agriculture and for the entire agro-food supply chain sector. This sector is of a key importance to overcome the worldwide challenges related to food security and food safety. Maria Lusser presented the objectives of the study for the IPTS in the context of the bioeconomy 2020 strategy. Daniel Traon, from Arcadia International, described the timelines and the methodology deployed to fulfil the objective of the study. Finally, before breaking down in working groups, Jean Claude Guillon, chairman of the ETP-Plant for the Future platform, presented the main objective of that platform and also indicated the high interest of the platform for the study launched by the IPTS.

Several participants to the workshop raised their concern concerning the scope of the study. They were considering that the data collection regarding the public capacities should cover the complete R&D process (from basic research to delivery of new cultivars) and not only the downstream part of it (applied plant breeding). Concern to which both the IPTS and Arcadia International answered that the main objective of the study is to fulfil the most important knowledge gap in the complete R&D process: the applied plant breeding sector. Indeed, several researches have already been carried out and publications already exist regarding public efforts and public capacities in the area of genomics and pre-breeding. As this is not the case for applied public plant breeding, the study research is mainly dedicated to cover this downstream part of the R&D seed process. In conclusions to this discussion, it was agreed to discuss this point during the next meeting between the IPTS and Arcadia International planned for mid-May and to come back to participants with an "official" answer confirming or modifying the scope of the study by latest end of May.

**Outcomes of the WGs session**

Each of the 42 workshop participants has been invited to join a given WG and assignments have been done by Arcadia based on the knowledge of each of them. This assignment of participants to individual WGS aimed at keeping equilibrium between the 3 different groups. We wanted to avoid having 80% of the participants in the food and feed WG and nearly no participants in the two others. In reality, about 50% of the workshop participants followed the discussions of the food and feed WG; 35% were present in the WG related to bioenergy and 7 persons followed the discussions of the WG on biochemical (most of them being Dutch). For us, this breakdown of participants in the 3 WGs seems to be a correct representation of the current plant breeding efforts per sector. To date, the majority of these efforts are dedicated to food and feed criteria, when efforts for biochemical are remaining marginal or are carried out for niche markets and not commodities.

*Results of WG1: Food and feed*

As an introduction, the rapporteur of this WG highlighted that the discussions were carried out in order to present an integrated view point of all R&D processes existing within the seed sector.

For the participants of this WG, it seems that the EU is looking at sustainable intensity = more concentrated agriculture (to produce more and to produce better on a reduced area (less acreage available for farming). Therefore productivity gains should be sought and especially in MS were yield and agriculture is not yet fully optimise and intensive (i.e. EU 12MS). Yield potential that is expressed in the VCU trials over the EU is not fully materialised in the producers' field. To the opinion of the participants this yield gap is certainly one of the most important concerns to be looked at and the public sector should play a key role on this "adaptation" of new cultivars and on the full expression of the yield potential in each individual farmer field.

The main breeding needs reported by the rapporteur are as follows:

1 Breeding for sustainable intensification of Food and Feed production via:
   - Traits and features important for enhancing:
      - Yield potential and yield stability (e.g. reproductive fertility)
      - Sustainability of crop and fruit-tree production
   - Higher yield potential and greater yield stability

2 Better understanding of the genetic basis of adaptation to climate change
   - Genotype x Environment interactions
   - Models to predict genotype performance (general combining adaptability and specific combining ability in hybrid crops)
3 Improve high-throughput phenotyping and genotyping
4 Improve nutritional quality and safety of food and feed; nutraceutical value of crops
5 Access to a broader genetic basis.
6 Target traits are:
   - Resistance to drought (e.g. roots), heat, freezing, salinity,ozone, etc.
   - Resource-use efficiency (e.g. WUE, NUE, PUE, etc.)
   - Resistance to pests and pathogens
   - Food and Feed quality and safety (e.g. mycotoxins in wheat)

In terms of technology to be used to fulfil these needs, it has been reported that traditional breeding will remain the main approach for the next decades. Backcrossing to be used for simple traits (e.g. quality, diseases resistance, etc). New breeding techniques could help speeding-up the breeding procedures (e.g. multiple cycles, double haploids, Marker Assisted selection, testing of unrestored hybrids, etc.). Speed is of the ascent of breeding and therefore any technique that can speed up the process is welcome. New techniques should also help turning autogamous crops in hybrid crops (already engaged for winter oil seed rape, wheat).

Traditional breeding should also profit from support of genomics assisted breeding which is becoming increasingly important and strategic) (e.g. genomic selection for complex quantitative traits such as heterosis, mapping and cloning of major loci for target traits. GMO techniques which are playing an increasing role in Americas and other non-EU countries play a marginal role in the UE due to public opposition, ideological prejudice and lack of political will to deregulate the commercialisation of GM cultivars. Provided the political and public climate will change, GMOs will play an increasingly important role in the medium-long term, particularly for improving quality and resistance to biotic stressors.

The main role of the public sector should be as follows:

1. Dissect and understand the genetic make-up and G x E interactions of target traits
2. Assemble platforms (e.g. SNPs) and collections of materials (e.g. introgression libraries, mutants, AM panels, etc.) useful to identify valuable alleles at target loci
3. Classify and preserve biodiversity
4. Improve orphan crops neglected by industry
5. Train and encourage private breeders to operate in a multidisciplinary context
6. Synergize traditional and molecular breeding
7. Educate the public about the merits of plant breeding and a healthy seed industry
8. Initiate breeding efforts on traits/criteria not considered by the private sector, prove usefulness and then transfer them the private sector (creation of public goods)

*Results of WG2: Non-food and feed: bio energy and of WG3: Non-food and feed: bio-chemicals*

As highlighted above, most of the actual breeding activities are dedicated to the development of cultivars leading to additional value (return for the farmers) and therefore yield is remaining the main criteria under breeders' consideration. When talking about bio energy and bio chemical traits, the audience wanted to highlight that these sectors are rather new and that they are considered rather differently by the breeders in the sense that food and feed is of public finality (food security and food safety) when bio chemicals and bioenergy are NOT of a public finality. They are 1) serving another industry by delivering high quality raw material and 2) will remain niche markets and not commodities.

Additional difficulties for breeders rely in the fact that these businesses are not mature yet with players that have not developed a stable long-term strategy. Therefore without knowing what plant breeders' customers want, it is difficult for breeders to establish long term breeding programs. A breeding cycle is of a minimum of 8 to 10 years and therefore breeders need to have evidences that there will be a return of investment before starting a new breeding program on a novel trait. This is where again the public sector could play a role of establishing preliminary work in order to help the private sector to jump in. Additionally, this type of research can stimulate the market.

Eventually, all new varieties integrating added value trait(s) for the biochemical and/or bioenergy businesses need to have all agronomic traits required for securing a good yield production in the farmer field. Agronomic traits need to be present first, and then new traits can be added. This argument explains why most of the breeding efforts dedicated to bio energy and bio chemicals have been initiated from the actual (food and feed) breeding efforts to the exception of the domestication of new species that have not yet proved usefulness.

Regarding the target traits, it is rather difficult to list them with security as long as the downstream business models have not stabilised (e.g. moving from 1st to 2nd biofuels generation).

All tools available to breeders and molecular scientists will be used to develop and integrate new traits in crops. Tools boxes have to be competitive and proportionate to the expected business size. Domestication efforts of new crops (e.g. *Calendula, Jatropha, Pongomia, Miscanthus, micro-algae*) are currently on-going but none of these efforts have delivered significant results to date. A limit to the development of these crops is the possibility that these wild crops become invasive species. This is a particular for Miscanthus in the EU and Jatropha in tropical areas (Jatropha is considered as an invasive crop in Australia and therefore import of seed forbidden). Miscanthus is a perennial that establishes and disseminate rather easily and quickly.

More than for food and fed, issues related to intellectual properties in one hand and identification preservation in the other hand are of key importance. In a niche market, if the supply chain cannot be established in co-existence with the commodity production chain, and if invention cannot be protected, breeding efforts in this area will not develop. These two elements may lead to the hypothesis that biotech tools may be preferred approaches for these needs as traits can be patented. For these cases, invention will be protected via trait patenting rather than via plants breeders rights.

**Assessment of the event by the participants**

Most of participants that have been contacted after the event have indicated that they have been happily surprised by the quality of the discussions. They also consider that this event should be further expanded as so many (other) elements have to be taken into consideration for completing the discussion.

In conclusion, they would like to further participate to the second part of the study and would welcome a dissemination meeting at the end of it. For them, the IPTS should organise it and should also present how it would proceed to valorise the work done under this project.

Representatives of the ETP Plants for the Future platform have also expressed their interest for further work and exchange of ideas in this area.

**An additional validation of the database listing crop/trait combinations has been performed as requested in the letter of acceptance for deliverable 2 from 06 June 2012 (topic 2)**. It was based on the following approach:

Step 1: As requested in the letter of acceptance for deliverable 2 from 06-06-2012, we have submitted a request to the listed individuals to comment on the 2 excel databases on 1)crop/trait combinations in the commercial pipelines of commercial breeders, and on 2)crops/traits combinations identified as relevant for the bio-based economy 2020 and climate change.

Based on the Arcadia's team experts feedback that are in contacts with the targeted persons, it became clear that none of the addressee were going to submit any comments as they considered the tables as not synthetic enough and too complicated.

Step 2: Based on this statement, we decided to launch a second round of validation that was sent to all persons that were present at the workshop. The approach was to ask them to validate the graph presented at the end of this file and to comment it whenever necessary.

We got answers from these experts in both written and verbal forms.

## Task 2A.1 Analysis of the evolution of the public plant breeding sector since 1950

This analysis have completed based a literature review and the production of a second EndNote library that compiles an inventory of the major publications presenting the evolution of the breeding sector in the EU since the end of World War II. It should be highlighted that the number of publications addressing this topic is extremely large and therefore the database that has been compiled by including only the key publications for each of the sub sector. Additionally a significant number of the publications listed in the EndNote libraries have been collected via the network of experts that the research team has consulted during the study and not from scientific electronic databases.

Literature search has been carried out in the major scientific electronic databases and online libraries as follows:

- Biological abstracts (BIOSIS Previews)
- Web of science (Science Citation Index) - Includes cited reference searching
- CAB Abstracts (agriculture citations) - International in scope. Plant breeding, horticulture, and grasslands are among its subjects. Includes the data from the TREECD (Forest Science Database).
- Agricola (U.S. agriculture literature citations)
- Scopus (all science fields) - Includes links to citing articles
- Online Journals
- Find Articles (multiple databases)
- Borrow Direct
- Interlibrary Loan
- Science Online Databases
- **http://www.mdpi.com**

- Additional and dedicated websites have been screened:

- International Center for Agricultural Research in the Dry Areas (ICARDA): **http://www.icarda.cgiar.org/Facelift.htm**
- European Cooperative Programme for Plant Genetic Resources (ECPGR): **http://www.ecpgr.cgiar.org/**
- International Community of Asexually Reproduced Ornamental and Fruit Plants (CIOPORA) **http://www.ciopora.org/service/press.html#.T316T_B6-So**
- International organisation **OECD** : **Http://www.oecd.org/department/0,3355,fr_2649_36831301_1_1_1_1_1,00.html**
- Information on breeding developments and public-private partnerships: **Http://www.upov.int/meetings/en/topic.jsp?group_id=73**
- Permanent International Committee for agricultural research: **http://www.iddri.org/Publications/Publications-scientifiques-et-autres/Sustainable-food-consumption-and-production-in-a-resource-constrained-world**
- GIPB website
- CIRAD: www.cirad.fr
- INRA (Institut Nationale de la Recherche Agronomique) : http://www.inra.fr
- Seedquest website (industry website)

The following keywords have been used:

- Breeding nurseries
- Breeding state of the art
- Breeding techniques evolution
- Breeding techniques state of the art
- Conventional plant breeding
- Field testing
- Field trials
- Hybridisation
- Intellectual properties
- Life science concept
- Life science history
- Marker assisted selection
- Molecular breeding
- Plant breeding
- Plant breeding biotechnology
- Plant breeding evolution
- Plant breeding history
- Plant breeding privatisation
- PPP relationship
- Private conventional plant breeding
- Private plant breeding
- Public conventional plant breeding
- Public plant breeding

- Public/private partnership
- Varieties protection
- Variety development
- Yield improvement

## Task 2A.2 Analysis of the complementary developments in the private sector

This summary is based on internal discussions between the project team members as most of them have a history within the private plant breeding sector, completed by outcomes of several interviews carried out with key industry experts, as follows:

- Bernard Le Buanec (former secretary general of the International Seed Federation and former breeder at Limagrain)
- Bert Scholte (Technical director ESA and former breeder and variety registration manager at CEBECO Seeds)
- Arnaud Petit (COPA-COGECA)
- Prof Yves Gallais (former plant breeding professor at INA-PG (FR))
- Suri Sehghal and Bill Niebur (former seed executives at Pioneer Hi-Breed international)
- Orlando Di Ponti (former seed executives at Nunhems – vegetable seed)

Based on internal brainstorming, the project team has developed a draft document which has been enriched by inputs collected during the interviews as listed above.

## Task 2 A.3 – Analysis of the evolution of the plant breeding sector in the EU in comparison to the global situation

A Third Country analysis has been conducted to analyse past and current evolution of the public plant breeding sector at international level.

The following contacts have been interviewed during the study.

<u>Australia</u>

- Dr. Richard Trethowan, Professor and Wheat Breedeer, University of Sydney.

<u>Brazil</u>

- Dr. Jurandir Magalhaes, Sorghum Researcher and Dr. Robert Schaffert, Sorghum Breeder, Brazilian National Maize and Sorghum Research Center, Embrapa. Sete Lagoas. Minas Gerais.
- Paulo Motta Ribas. Consultant at Valor Orientações Agropecuarias Ltda.

<u>Chile</u>

- Dr. Julio Kalazich, Potato Breeder, Potato National Center, Regional Research Center of Remehue.

<u>United States</u>

- Dr. Ann Marie Thro, National Program Leader, Plant Breeding and Genetic Resources, National Institute for Food and Agriculture (NIFA), USDA. Washington, D.C.

IRRI (Indonesia, Philippines, Vietnam)

- Dr. Casiana Vera Cruz, Researcher, International Rice Research Institute, Los Baños.
- Dr. Arelene Julia Malabayabas, Researcher, International Rice Research Institute, Los Baños.
- Dr. Edilberto Redoña, Global Coordinator of the International Network for Genetic Evaluation of Rice (INGER), IRRI, Los Baños.

## Task 2 B – Mapping the current status, capacity and potential of the public plant breeding sector (including public/private partnership)

A survey was carried out during Task 2 of the study. It was based on two separate and complementary questionnaires.

- A General Survey to collect information regarding resources and capacities of the public plant breeding sector in the development and release of new cultivars;
- A Specific Survey addressing pre-breeding activities in indirect support to development of commercial cultivars.

The two survey questionnaires have been drafted by the research team and validated by the Commission services before launching.

The General Survey was directed to the public plant breeding sector representatives and directly to plant breeders. Institutes and universities in each of the EU 27 MS were contacted by the research team members and the questionnaire was also accessible through the web site **http://www.plantbreedingstudy.com/** from mid-June to end of September.

In total the General Survey has been sent to 281 representatives of the public sectors of 29 countries (EU 27 MS + Norway + Serbia). Each of the addressees has been invited to further forward the questionnaire in order to allow completeness.

The identification of the relevant institutes has been carried out by each member of the research team. Each team expert has been assigned one or several MS to follow during the data collection process. For each MS, their responsibility was to identify public institutes that should complete the questionnaire, send this general questionnaire to these research institutes and follow-up closely to secure a response by end of July. This identification was based on direct contact with key persons per MS (Variety registration officers, seed industry representatives, other academic experts). Several approaches were taken in order to triangulate information collected from different sources.

The responsibility of each expert was as follows:

| | J.Gennatas | A. Ayerdi | A.van Elsen | V.Negri | Arcadia |
|---|---|---|---|---|---|
| **AT** | | | | | X |
| **BE** | | | | | X |
| **BG** | | | | | X |
| **CY** | | | | | X |
| **CZ** | | | | | X |
| **DK** | | | | | X |
| **DE** | | | X | | |
| **EE** | X | | | | |
| **EL** | X | | | | |
| **ES** | | X | | | |
| **FI** | | | | | X |
| **FR** | X | | | | |
| **HU** | | | | | X |
| **IE** | | | | | X |
| **IT** | | | | X | |
| **LT** | X | | | | |
| **LU** | X | | | | |
| **LV** | X | | | | |
| **MT** | X | | | | |
| **NL** | | | X | | |
| **PT** | | X | | | |
| **PL** | | | X | | |
| **RO** | | | | | X |
| **SE** | | | | | X |
| **Serbia** | | | | | X |
| **SL** | | | | | X |
| **SK** | | | | | X |
| **UK** | | | X | | |

The general survey has been launched mid-June, after acceptation of the questionnaire by the Commission.

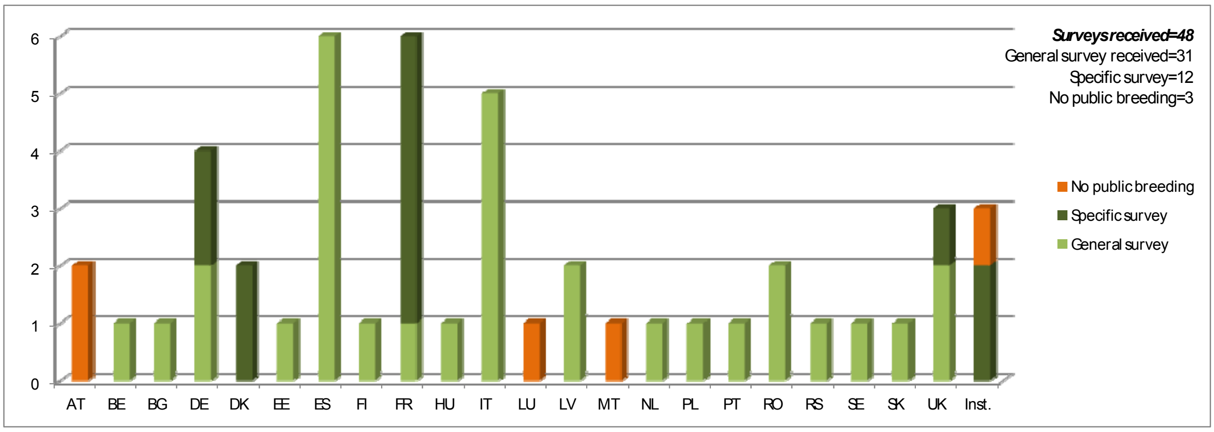
Finally, the questionnaire has been published on the **www.plantbreedingstudy.com** web site.

The Specific Survey (which was optional) was launched via the EPSO secretariat that distributed the survey to all its members.

Beginning of August, 142 reminders were sent. For the specific, EPSO sent a reminder to its members at the same time

The General Survey questionnaire has been returned by 48 respondents from 21 MS of which 31 questionnaires have been fully completed. As regard to the Specific Survey questionnaire, only 12 organisations/institutions completed it. Three MS have indicated that no public plant breeding activities were occurring in their country any longer. Therefore there was no need for them to fill the questionnaire. For the 5 other MS for which it had been concluded that no public breeding is occurring, information has been gathered based on the common knowledge of the study team experts, discussions with other experts and variety registration officers.

**Surveys responses by countries**




Based on additional contacts with officials in charge of variety registration, and based on the common knowledge of the research team, it has identified that no public breeding occurs in MS not listed in the above figure (CY, CZ, LT, SL, SK).

The number of responses per MS does not provide any information regarding the number of public institutes or universities involved in breeding as some MS (e.g. France, Romania) have submitted a coordinated answer including all efforts within the country when in other MS each institute has responded separately.

Further follow-up have been carried by sending email reminders to institutes that didn't fill the questionnaire. When required, these direct email reminders have been followed by phone calls.

In the case of Bulgaria and Serbia, as we have not got any answer back from the national institute in charge of public breeding, we have extracted data from the GIPB website (**http://gipb.fao.org/Web-FAO-PBBC/**).

Regarding Poland, we have completed the methodology described above by two complementary approaches:

- Direct approach during national seed events that took place in early September by a local well recognised expert (Dr Karol Marciniak);
- Official letter from the IPTS to the different relevant institutes.

This approach has led to the submission of one additional survey questionnaire when we were expecting the response from 6 different institutes.

Raw data from the survey questionnaires (generic and specific) have been compiled in an Excel database that has been used by the study team for the data analysis of which the results are presented in the core part of this report. Only significant results have been considered in the main part of the report.

Data gaps have been identified and further direct contacts with respondents to the general survey have been taken on a case by case basis. This task has been continued till beginning of October.

## Quality management and risk register

To ensure that the services provided fully meets the expected professional standards, the research team worked on the basis of quality procedures to control and ensure high quality and effective monitoring of the services and works supplied to the Commission in execution of the contract.

Our quality management refers to the implementation of a series of procedures:

- Kick-off meeting with the client to ensure full understanding of the required services;
- Customised project team to ensure the most appropriate sets of expertise, specialty and competences given the distinctive features of the assignment;
- *Ex-ante* quality assurance plan, based on EU quality assessment (e.g. validation of the surveys and adaptations must have the Commission's prior approval);
- Respect for deadlines*:* all team members are highly professional and are used to delivering under tight deadlines. By experience, they have learned to make reliable judgements of workloads, enabling full respect of deadlines by pragmatically implementing the tools and approaches presented above. The kick-off meeting and development of the detailed action plan for the consortium's team of experts will furthermore clarify from the beginning the expected contributions from each person involved at the different stages of the project. This will allow to 'block' in advance the indicated number of man-days per person in their planning, ensuring sufficient availability when required and enhancing the respect of deadlines. Whenever difficulties are encountered by a team member, this will be shared with other team members so that (alternative) solutions can be found as soon as possible and that work is not unnecessary delayed;
- The application of our internal quality guidelines;
- Notification of any reduction in capacity to the Commission and full replacement with a same level of expertise proposed within ten working days;
- Delivery of a progress report in June 2012 to the JRC-IPTS.

**Additionally, a risk register has been maintained an updated during the complete duration of the contract. As of 10 November 2012, it reads as follows:**

| N° | Issue | Risk management approach | Owner |
|---|---|---|---|
| 1 | Maintaining client-consultant communication | Bi-monthly telephone 'meetings' to review progress and discuss issues. | Arcadia/JRC-IPTS |
| 2 | Effective and timely delivery of outputs | Weekly monitoring of progress of task completion to rapidly identifying possible difficulties and remedying them in a short time span. | Arcadia & experts |
| 3 | Scope and complexity of study challenges team abilities | Internal project management meetings.<br>Quality review of deliverables. | Arcadia & experts |
| 4 | Quality assessment | Review of the draft deliverables by the research team experts before submission to COM | Arcadia & experts |
| 5 | Project fits not enough to Commission's performance criteria | Quality control manager to review all deliverables against Commission's performance review criteria | Arcadia |
| 6 | Understanding of project's objective | Fostering of study objectives via networking, face to face interviews, the workshop organized 11 April 2012, and the dedicated website (www.plantbreedingstudy.com) | Arcadia & experts |
| 7 | Delays in answering the general survey questionnaire | Email reminders sent to relevant institutes followed by direct phone contacts | Arcadia and Experts |
| 8 | Delays in answering the general survey questionnaire (case of Poland) | Same approach than 7 + Direct face to face contacts and official letter sent by IPTS (based on Arcadia initiative) to the Polish institutes | Arcadia/IPTS and Experts |
| 9 | Generic survey questionnaires provide insufficient data to support analysis | Email and phone contacts with the respondents. Increased resources allocated to telephone interviews. | Arcadia and Experts |
| 10 | Delays in answering the specific survey | Reminder sent to EPSO members by EPSO secretariat | Arcadia/EPSO |

# ANNEX 4 : THE GENERAL SURVEY QUESTIONNAIRE

IDENTIFICATION DATA

- Country:
- Name of the organisation:
- Name of the person completing the questionnaire:
- Position in terms of role and responsibility with respect to the area of competences below identified:
- Phone number:
- E-mail:

Please indicate for which year you report answers to the questions:

Please indicate for which sections you provide answers to:

| Section | Yes/No |
|---|---|
| *Section 1:* Plant breeding efforts and resources (input) | |
| *Section 2:* Plant breeding results (outputs) | |
| *Section 3:* Public/private partnership (other than commercial relations) and the future of public plant breeding | |

## Section 1: Plant breeding efforts and resources (inputs)

**1) Please indicate in which of the following activities you are involved:**

| Activity | Yes/No |
|---|---|
| 1) Genomics | |
| 2) Pre-breeding | |
| 3) Molecular breeding in support to activities 4 to 8 (MolBreed) | |
| 4) Germplasm collection and caracterisation (GermCar) | |
| 5) Variety development (creation of potential commercial varieties) (VarDev) | |
| 6) Variety testing (testing of candidates commercial commercial (VarTest) | |
| 7) Parental and first generation seed production of commercial varieties (ParSeedProd) | |
| 8) Commercial seed production (ComSeedProd) | |
| 9) Marketing of seed varieties (SeedMark) | |

*In case, you have only answered "Yes" for activity 1 and/or for activity 2 please briefly describe your efforts related to these activities (max. 1 page).*

*1.1 Thanks to breakdown your activities according to the following list of crops*

| ***Crop*** | **3)** *MolBreed* | **4)** *GermCar* | **5)** *VarDev* | **6)** *VarTest* | **7)** *ParSeedProd* | **8)** *ComSeedProd* | **9)** *SeedMark* |
|---|---|---|---|---|---|---|---|
| *Example* | *Yes* | *No* | *Yes* | *No* | *No* | *No* | *No* |
| Winter wheat | | | | | | | |
| Maize | | | | | | | |
| Triticale | | | | | | | |
| Other cereals | | | | | | | |
| Sunflower | | | | | | | |
| Winter OSR | | | | | | | |
| Soybean | | | | | | | |
| Other oilseeds | | | | | | | |
| *Gramineae* | | | | | | | |
| legumes | | | | | | | |
| Vine | | | | | | | |
| Apple | | | | | | | |
| Other fruit plants | | | | | | | |
| Potatoes | | | | | | | |
| *Brassiceae* | | | | | | | |
| lettuces | | | | | | | |
| Tomatoes | | | | | | | |
| Sugar beet | | | | | | | |
| Hop | | | | | | | |
| Cotton | | | | | | | |
| Other industrial crops | | | | | | | |
| Maize for ethanol | | | | | | | |
| Oil seed rape for biofuel | | | | | | | |
| *Miscanthus* | | | | | | | |
| *Jatropha* | | | | | | | |
| Poplar | | | | | | | |
| Maize for biochemical | | | | | | | |
| Others for biochemical | | | | | | | |
| ***Others: please specify*** | | | | | | | |

**2) Please indicate your organisation's financial resources & staff and the proportion that was allocated to the different applied plant breeding activities in the period 2000-2010**

| | **Financial resources (in K Euros)** | | **Staff with degree in plant breeding (no of FTEs)** | | **Other academic personal (no of FTEs)** | |
|---|---|---|---|---|---|---|
| | **2000** | **Most recent year** | **2000** | **Most recent year** | **2000** | **Most recent year** |
| *example* | *300* | *350* | *5* | *4* | *5* | *5* |
| *GermCar* | | | | | | |
| *MolBreed* | | | | | | |
| *VarDev* | | | | | | |
| *VarTest* | | | | | | |

3) **Thanks to breakdown your efforts according to the following list of crops (provide information for crops you are working on)**

| ***Crop*** | **Financial resources** ***(in K Euros)*** | | **Staff with degree in plant breeding** ***(number of FTEs)*** | | **Other academic personal** ***(number of FTEs)*** | |
|---|---|---|---|---|---|---|
| | **2000** | **Most recent year** | **2000** | **Most recent year** | **2000** | **Most recent year** |
| *example* | *122* | *135* | *6* | *10* | *6* | *10* |
| Winter wheat | | | | | | |
| Maize | | | | | | |
| Triticale | | | | | | |
| Other cereals | | | | | | |
| Sunflower | | | | | | |
| Winter OSR | | | | | | |
| Soybean | | | | | | |
| Other oilseeds | | | | | | |
| *Gramineae* | | | | | | |
| legumes | | | | | | |
| Vine | | | | | | |
| Apple | | | | | | |
| Other fruit plants | | | | | | |
| Potatoes | | | | | | |
| *Brassiceae* | | | | | | |
| lettuces | | | | | | |
| Tomatoes | | | | | | |
| Sugar beet | | | | | | |
| Hop | | | | | | |
| Cotton | | | | | | |
| Other industrial crops | | | | | | |
| Maize for ethanol | | | | | | |
| Oil seed rape for biofuel | | | | | | |
| *Miscanthus* | | | | | | |
| *Jatropha* | | | | | | |
| Poplar | | | | | | |
| Maize for biochemical | | | | | | |
| Others for biochemical | | | | | | |
| ***Others: please specify*** | | | | | | |

4) **Please provide information if expertise, equipment and facilities are available to use biotechnology, especially transgenesis or new plant breeding techniques (such as cisgenesis, intrageneses, ZFN, meganuclease techniques, ODM, etc.)**

## 5) <u>Are you contracting IN activities from outside your organisation to complement your internal plant breeding activities?</u>

| Activity | Contracting IN activities *(in K Euros)* | Of which from private organisations (in %) | Of which from other public organisations (in %) |
|---|---|---|---|
| *example* | *450* | *70%* | *30%* |
| GermCar | | | |
| MolBreed | | | |
| VarDev | | | |
| VarTest | | | |

*5.1. Thanks to breakdown your contracting IN activities according to the following list of crops (provide information for crops you are working on)*

| *Crop* | Contracting IN activities *(in K Euros)* | Of which from private organisations (in %) | Of which from other public organisations (in %) |
|---|---|---|---|
| *example* | *30* | *90%* | *10%* |
| Winter wheat | | | |
| Maize | | | |
| Triticale | | | |
| Other cereals | | | |
| Sunflower | | | |
| Winter OSR | | | |
| Soybean | | | |
| Other oilseeds | | | |
| *Gramineae* | | | |
| legumes | | | |
| Vine | | | |
| Apple | | | |
| Other fruit plants | | | |
| Potatoes | | | |
| *Brassiceae* | | | |
| lettuces | | | |
| Tomatoes | | | |
| Sugar beet | | | |
| Hop | | | |
| Cotton | | | |
| Other industrial crops | | | |
| Maize for ethanol | | | |
| Oil seed rape for biofuel | | | |
| *Miscanthus* | | | |
| *Jatropha* | | | |
| Poplar | | | |
| Maize for biochemical | | | |
| Others for biochemical | | | |
| ***Others: please specify*** | | | |

## 6) Are you contracting OUT activities to other plant breeding activities?

| Activity | Contracting out activities (in K Euros per year) | Of which to private organisations (in %) | Of which to other public organisations (in %) |
|---|---|---|---|
| *Example* | *200* | *20%* | *80%* |
| GermCar | | | |
| MolBreed | | | |
| VarDev | | | |
| VarTest | | | |

*6.1. Thanks to breakdown your contracting OUT activities according to the following list of crops (provide information for crops you are working on)*

| *Crop* | Contracting out activities (in K Euros per year) | Of which to private organisations (in %) | Of which to other public organisations (in %) |
|---|---|---|---|
| *example* | *200.000* | *50%* | *50%* |
| Winter wheat | | | |
| Maize | | | |
| Triticale | | | |
| Other cereals | | | |
| Sunflower | | | |
| Winter OSR | | | |
| Soybean | | | |
| Other oilseeds | | | |
| *Gramineae* | | | |
| legumes | | | |
| Vine | | | |
| Apple | | | |
| Other fruit plants | | | |
| Potatoes | | | |
| *Brassiceae* | | | |
| lettuces | | | |
| Tomatoes | | | |
| Sugar beet | | | |
| Hop | | | |
| Cotton | | | |
| Other industrial crops | | | |
| Maize for ethanol | | | |
| Oil seed rape for biofuel | | | |
| *Miscanthus* | | | |
| *Jatropha* | | | |
| Poplar | | | |
| Maize for biochemical | | | |
| Others for biochemical | | | |
| ***Others: please specify*** | | | |

## Section 2: Plant breeding results (outputs)

**7) How many varieties have you released (made available to producers) during the last 10 years per crop or group of crops you are breeding for and what is the evolution during the last 10 years (Increase, Equal, Decrease)?**

| ***Crop*** | *Total number of released varieties* | | *Traits concerned (specify the 3 main ones)* | *Number of transgenic varieties* | *Evolution during the last 10 years (equal, decrease; increase)* | *Main reason of this evolution* |
|---|---|---|---|---|---|---|
| | *in the 2000-2005 period* | *in the 2005-2010 period* | | | | |
| *Example* | 10 | 12 | *Yield, disease resistance* | 0 | *Decrease* | *Budget reduction* |
| ***Total*** | | | | | | |
| *Of which* | | | | | | |
| Winter wheat | | | | | | |
| Maize | | | | | | |
| Triticale | | | | | | |
| Other cereals | | | | | | |
| Sunflower | | | | | | |
| Winter OSR | | | | | | |
| Soybean | | | | | | |
| Other oilseeds | | | | | | |
| *Gramineae* | | | | | | |
| legumes | | | | | | |
| Vine | | | | | | |
| Apple | | | | | | |
| Other fruit plants | | | | | | |
| Potatoes | | | | | | |
| *Brassiceae* | | | | | | |
| lettuces | | | | | | |
| Tomatoes | | | | | | |
| Sugar beet | | | | | | |
| Hop | | | | | | |
| Cotton | | | | | | |
| Other industrial crops | | | | | | |
| Maize for ethanol | | | | | | |
| Oil seed rape for biofuel | | | | | | |
| *Miscanthus* | | | | | | |
| *Jatropha* | | | | | | |
| Poplar | | | | | | |
| Maize for biochemical | | | | | | |
| Others for biochemical | | | | | | |
| ***Others: please specify*** | | | | | | |

## 8) Where are varieties you have developed been placed on the market?

- In my domestic market only: Yes/No
- In other EU countries: Yes/No Which ones:
- In other Non EU countries: Yes/No

*8.1. Thanks to breakdown your answer according to the following list of crops (provide information for crops you are working on)*

| ***Crop*** | **In my domestic country (Yes/No)** | **In other EU countries (list of countries)** | **In other Non EU countries (list of countries)** |
|---|---|---|---|
| Winter wheat | | | |
| Maize | | | |
| Triticale | | | |
| Other cereals | | | |
| Sunflower | | | |
| Winter OSR | | | |
| Soybean | | | |
| Other oilseeds | | | |
| *Gramineae* | | | |
| legumes | | | |
| Vine | | | |
| Apple | | | |
| Other fruit plants | | | |
| Potatoes | | | |
| *Brassiceae* | | | |
| lettuces | | | |
| Tomatoes | | | |
| Sugar beet | | | |
| Hop | | | |
| Cotton | | | |
| Other industrial crops | | | |
| Maize for ethanol | | | |
| Oil seed rape for biofuel | | | |
| *Miscanthus* | | | |
| *Jatropha* | | | |
| Poplar | | | |
| Maize for biochemical | | | |
| Others for biochemical | | | |
| ***Others: please specify*** | | | |

## 9) Are you generating revenues from:

- The direct marketing of your own varieties: Yes/No % of total revenue: **%**
- Royalties of varieties you have delegated marketing of to commercial partner(s):
  Yes/No % of total revenue: **%**
- Incomes from contracting out services to other public and/or plant breeding companies:
  Yes/No % of total revenue: **%**

**Thanks to indicate your total revenues (in K Euros) in the most recent year: K Euros**

**What has been the evolution of your total revenue during the last 10 years?** *(example: increase by 30%)***:**

**What is the percentage of public funding in your yearly budget that complements your revenues?** **%**

**What has been the evolution of your public funding during the last 10 years?** *(example: increase by 30%)***:**

*9.1. Thanks to breakdown your answer according to the following list of crops (provide information for crops you are working on)*

| ***Crop*** | **Total revenues *(in K Euros)*** | **% of budget coming from public funding** | **% of budget coming from direct marketing of your own varieties** | **% of budget coming from royalties of varieties delegated to commercial partner(s)** | **% of budget coming from incomes from contracting out services** |
|---|---|---|---|---|---|
| Winter wheat | | | | | |
| Maize | | | | | |
| Triticale | | | | | |
| Other cereals | | | | | |
| Sunflower | | | | | |
| Winter OSR | | | | | |
| Soybean | | | | | |
| Other oilseeds | | | | | |
| *Gramineae* | | | | | |
| legumes | | | | | |
| Vine | | | | | |
| Apple | | | | | |
| Other fruit plants | | | | | |
| Potatoes | | | | | |
| *Brassiceae* | | | | | |
| lettuces | | | | | |
| Tomatoes | | | | | |
| Sugar beet | | | | | |
| Hop | | | | | |
| Cotton | | | | | |
| Other industrial crops | | | | | |
| Maize for ethanol | | | | | |
| Oil seed rape for biofuel | | | | | |
| *Miscanthus* | | | | | |
| *Jatropha* | | | | | |
| Poplar | | | | | |
| Maize for biochemical | | | | | |
| Others for biochemical | | | | | |
| ***Others: please specify*** | | | | | |

**Are you generating revenues from other sources than the ones mentioned above?**

**Yes/No**

*If yes, thanks to provide details:*

## Section 3: Public/private partnership (other than commercial relations)

10) Are you involved in private partnership others than the ones related to commercial relations and already described under Section 2:

    Yes/No

| *Please briefly describe the projects* |
|---|
| |

## Section 4: The future of public plant breeding.

11) Indicate the aspects your organisation considers the most limiting for the success of the plant breeding programmes. In the second column (2012) identify the ones that are currently relevant and in the first column (2000) indicate the ones important 10 years ago. Please only write the main five and sort them in order of importance (1= the most important, 5= the least important)

| Aspects | 2000 | 2012 |
|---|---|---|
| *Lack of adequate public funding to run modern applied plant breeding schemes* | | |
| *Inadequate number of plant breeders for each crop* | | |
| *Inadequate resources to develop and set-up a field testing network* | | |
| *Inadequate resources to set-up molecular breeding capacities* | | |
| *Lack of knowledge about the use of modern plant breeding techniques* | | |
| *Limited access to germplasm* | | |
| *Issues regarding set-up IP agreements with private companies* | | |
| *Competitiveness issues on domestic markets* | | |
| *Limited access to non-domestic markets* | | |
| *Others: please specify:* | | |

# ANNEX 5 : SPECIFIC SURVEY QUESTIONNAIRE

IDENTIFICATION DATA

- Country:
- Name of the organisation:
- Name of the person completing the questionnaire:
- Position in terms of role and responsibility with respect to the area of competences below identified:
- Phone number:
- E-mail:

Please indicate for which year you report answers to the questions:

12) **For how many years has you organisation been involved in activities in support to applied plant breeding activities?**

_______ years

13) **Can you please estimate the number of scientists (in Full Time Equivalent) involved in activities supporting applied plant breeding?**

| | 2000 | 2010 |
|---|---|---|
| Number in scientists (in FTE) in support to applied plant breeding | | |
| *Of which for* | | |
| *Pre-breeding* | | |
| *Genomics* | | |
| *Other: please specify* | | |

**14) Can you please list the research projects carried-out under a public/private partnership in which your organisation is associated?**

| Research project | Number of scientists FTE involved | Funding |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

**15) Are you generating revenues from the seed business actors?**

Yes/No

If yes, please describe how:

| |
|---|
| |

*16)* **Indicate the aspects your organisation considers the most limiting for the success of the plant breeding programmes**. *In the second column (2012) identify the ones that are currently relevant and in the first column (2000) indicate the ones that were important 10 years ago. Please only write the main five ones and sort them (1= the most important, 5= the least important)*

| **Aspects** | **2000** | **2012** |
|---|---|---|
| *Lack of adequate public funding to run modern applied plant breeding schemes* | | |
| *Lack of adequate public plant breeding funding to develop genomic knowledge and associated tools* | | |
| *Inadequate resources to set-up molecular breeding capacities* | | |
| *Lack of knowledge about the use of modern plant breeding techniques* | | |
| *Inadequate number of plant breeders for each crop* | | |
| *Limited access to germplasm* | | |
| *Issues regarding set-up IP agreements with private companies* | | |
| *Others: please specify:* | | |

# ANNEX 6: LIST RELEVANT INSTITUTES

The following table lists all relevant institutes (i.e. institutes or universities that are currently involved in the development of commercial varieties) that have been identified during the study.

The records in bold lists the institutes that have not completed the General Survey questionnaire. It should also be noticed that the General Survey questionnaire for Bulgaria and Serbia have been completed based on a literature search (GIPB country reports) as no answers from these countries have been provided.

| MS | Organisation name |
|---|---|
| BE | Institut voor Landbouw en Visserijonderzoek (ILVO) - Plant Sciences Unit Head |
| **BG** | **National Agricultural Advisory Service** |
| DE | Forschungszentrum Jülich GmbH |
| DE | Institute of Forest Genetics |
| **DE** | **International Council for the Study of Virus and other Graft Transmissible Diseases of Fruit Crops (ICVF)** |
| DE | Julius Kuehn-Institute, Institute for Grapevine Breeding Geilweilerhof |
| EE | Jögeva Plant Breeding Institute |
| ES | Council of Scientific Research (CSIC) |
| ES | ESTACION EXPERIMENTAL AULA DEI (EEAD) |
| ES | Instituto Valenciano de Investigaciones Agrarias (IVIA) |
| ES | Institute of Agriculture and Food Research and Technology |
| ES | Mision Biologica de Galicia (MBG) |
| FI | MTT Agrifood Research Finland, Horticulture |
| FR | Institut de Génétique, Environnement et Protection des Plantes ( IGGEP) |
| FR | Institut National de la Recherche Agronomique (INRA) |
| **GR** | **National Agricultural Research Foundation (NAGREF)** |
| HU | University of Pannonia |
| IT | Consiglio per la ricerca e la sperimentazione in agricoltura (CRA) |
| IT | University of Bologna Department of Agroenvironmental Sciences and Technology |
| **LT** | **State Priekuli Plant Breeding Institute** |
| LV | Latvia State Institute of Fruit-Growing, Dobele |
| NL | Wageningen University & Research centre (WUR) |
| **PL** | **Institute of Plant Physiology (IFR- Krakow)** |
| **PL** | **Institute of Plant Genetics (IGR-Poznan)** |
| PL | IHAR (Institute of Plant Breeding and Acclimatization) |
| **PL** | **Poznań University of Life Sciences** |
| PL | Research Institute of Horticulture |
| **PL** | **Warsaw University of Life Sciences (SGGW)** |
| PT | Instituto Nacional de Investigação Agrária e Veterinária (INIA-INRB) |
| RO | National Agricultural Research and Development Institute |
| RO | Sibiu Lucian Blaga University |
| **RS** | **Institute of Field and Vegetable Crops, Novi Sad** |

| MS | Organisation name |
| --- | --- |
| SE | Swedish University of Agriculture Science (SLU) |
| SK | Ústredný Kontrolný a Skúšobný Ústav Poľnohospodársky (UKSUP) |
| **UK** | **James Hutton Institute** |
| UK | Mylnefield Research Services Ltd |
| UK | Wye Hops Limited |

# ANNEX 7: BIBLIOGRAPHY FOR SECTION 3 OF THE REPORT


**Abberton, M**. 2010. The Future of Plant Breeding.wmv.

**Abberton, M.** 2010. Facing the challenge of climate change: the role of plant breeding.

**Annevelink, E.** 2006. First workshop on the possibilities of biorefinery concepts for the industry. In E. d. J. R. v. R. R. W. R. Zwart (Ed.). Biorefinery.

**An Najah University**, 2000, History and role of plant breeding is society

**Bouis, H. E**. 2003. The economics of plant breeding as an agricultural strategy for reducing micronutrient malnutrition, Impacts of Agriculture on human health and nutrition.

**Carlsson, A. S.** 2009. Plant oils as feedstock alternatives to petroleum - A short survey of potential oil crop platforms: Pages: 665-670. Elsevier.

**Carlsson, A. S.** 2011. Replacing fossil oil with fresh oil – with what and for what? In A. G. G. Jenny Lindberg Yilmaz, Sten Stymne, Per Hofvander (Ed.): 113: 812–831. . Eur. J. Lipid Sci. Technol.

**Ceccarelli, S.** 2010. Plant breeding and climate change. In M. M. S. Grando, M. Michael, R. Haghparast,M. Rahmanian, A. Taheri, A. Al-Yassin, A. Benbelkacem, M. Labdi,H. Mimoun, & M. Nachit (Eds.): 627-637. The Journal of Agricultural Science.

**Ceccarelli S. et al.. 1994.Genotype by environment interaction and international breeding programmes. Experiment agriculture/Volume 3°/ issue 02 Chakraborty, S.** 2011. Climate change, plant diseases and food security: an overview. In A. C. Newton (Ed.): 2–14,. Plant Pathology.

**Choo, T. M.** 2010. Breeding Barley for Resistance to Fusarium Head Blight and Mycotoxin Accumulation, in Plant Breeding Reviews, (ed J. Janick): Volume 26. John Wiley & Sons, Inc., Oxford, UK.

**Clement, S.** 2002. A long way ahead, understanding and engineering plant metal accumulation: 309-315. Trends in plant sciences 7,7.

**Cooper et al.,** ***1996. Plant adaptation and crop improvement. book. CAB International.***

**Dethier, J.-J., & Effenberger, A.** 2012. Agriculture and development: A brief review of the literature, Economic Systems.

**Duvick, D. N.** 2005. The Contribution of Breeding to Yield Advances in maize (Zea mays L.). In L. S. Donald (Ed.), Advances in Agronomy, Vol. Volume 86: 83-145: Academic Press.

**Duvick, D. N.** 2001. Prospects for reducing fumonisin contamination of maize through genetic modification. PubMed.

**Duvik, D. N.** 1986, Plant breeding: past achievements and expectations for the future, Econ. Bot. 40:289-297

**European Parliament**, 2008, Agriculture and rural development, the competition between food crops and non-food crops for energy: what are the effects on agricultural structures and on the use of land?

**European Technology Platform**. 2006. Survey on Future Plant research activities in Europe.

**FCEC.** 2011. Final Reports on the evaluation on the EU *acqui*s on marketing of seed varieties

**Frey,** 1971, improving crop yields through plant breeding. Am. Soc. Agron. Spec. Publ. 20:15-58

**Heller, N. E.** 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. In E. S. Zavaleta (Ed.): 142: 114-132. Biological Conservation.

**Hood, E. E.** 2011. The Bioeconomy: A New Era of Products Derived from Renewable Plant-Based Feedstocks. In P. N. R. Powell (Ed.). Wiley.

**Howard, J**. 2005. Bioindustrial and Biopharmaceutical Products Produced in Plants. In E. Hood (Ed.), Advances in Agronomy, Vol. Volume 85: 91-124: Academic Press.

**IPBE. 2011.** Towards green chemistry and green materials. In P. B. s. W. BbE) (Ed.), Executive summary: pp.1-8.

**Jongschaap, R. E. E.** 2010. Highlights of the Jatropha curcas Evaluation Program (JEP): crop management and the fate of press-cake and other by-products with its effects on environmental sustainability. In F. J. d. R. L.R. Montes Osorio, E.N. van Loo (Ed.). International conference on Jatropha curcas 2010. ICJC2010, 1-2 November 2010, Groningen, The Netherlands.

**Koops, A. J.** 2010. Research vision on Plant Breeding for Bio-based production chains. In L. M. Trindade (Ed.), short summary: pp.1-2. report 232.

**Lehoczki-Krsjak, S**. 2010. Prevention of Fusarium mycotoxin contamination by breeding and fungicide application to wheat: 616-628. Food Addit Contam Part A Chem Anal Control Expo Risk Assess. 27(5).

**Lobell, D.** 2008. Prioritizing climate change adaptation needs for food security in 2030. In T. C. Burke MB, Mastrandrea MD, Falcon WP, Naylor RL (Ed.): 319(5863): 5607–5610. Science.

**Loyce, C.** 2012. Growing winter wheat cultivars under different management intensities in France: A multicriteria assessment based on economic, energetic and environmental indicators, Field Crops Research, Vol. 125: 167-178.

**Lucciani**.2004.Etude du progress génétique chez différentes espèces de grandes cultures. GEVES Report. Luck, J. 2011. Climate change and diseases of food crops. In many (Ed.): 113-121. Plant Pathology.

**Macek.** 2002. Accumulation of cadmium by transgenic tobacco: 711-760. Acta Biotecnol 52.

**Mascia, P.** 2004. Safe and acceptable strategies for producing foreign molecules in plants. In R. B. Flavell (Ed.), Current Opinion in Plant Biology, Vol. 7: 189-195.

**Monty,** 2006, Agronomic performances and yield stability of pea-barley intercropping in European organic farming system. Poster at: Joint Organic Congress, Odense, Denmark, May 2006

**Noack, R.** 2003. BREEDING | Selection Strategies for Disease and Pest Resistance. In V. R. Editor-in-Chief: Andrew (Ed.), Encyclopedia of Rose Science: 49-55. Oxford: Elsevier.

**Oliver, R. J.** 2009. Second generation bioenergy crops and climate change: a review of the effects of elevated athmospheric CO2 and drought on water use and the implication for yield. In J. W. Finch, Taylor, G (Ed.): 97-114. Global Change Biology Bioenergy.

**Ortiz-Monasterio, J. I.** 2007. Enhancing the mineral and vitamin content of wheat and maize through plant breeding. In N. Palacios-Rojas, E. Meng, K. Pixley, R. Trethowan, & R. J. Peña (Eds.), Journal of Cereal Science, Vol. 46: 293-307.

**Pfeiffer, W. H.** 2008. Biofortification: Breeding Micronutrient-Dense Crops, in Breeding Major Food Staples In P. P. M. S. Kang, McClafferty, B. (Ed.). Blackwell Publishing Ltd, Oxford, UK.

**Pfeiffer et al**. Enhancing genetic grain yield potential and yield stability in durum wheat available at http://ressources.ciheam.org/om/pdf/a40/00600009.pdf

**Pilon-Smith, E.** 2002. Phytoremediation of metals using transgenic plants: 439-456. Crit. reviews, Plant Science 21 (5).

**Plantstress database online**.

**Pray, C. E.** 2007. Chapter 49 Private Agricultural Research. In P. P. R. Evenson, Fuglie, Keith O, Johnson, Daniel K. N. (Ed.), Handbook of Agricultural Economics, Vol. Volume 3: 2605-2640: Elsevier.

**Ree, R. V**. 2007. Status Report Biorefinery. In E. Annevelink (Ed.).

**Reynolds, M. P.** 2010. Climate change and crop production, CABI series in climate change ;. CABI: Wallingford, Oxfordshire, UK ;.

**Reynolds, M. P.** 2012. Global crop improvement networks to bridge technology gaps. In B. G. J. Hellin, P. Kosina, K. Sonder, P. Hobbs, H. Braun (Ed.): 40920. J. Exp. Bot.

**Royal Society of Bangor University.** 2009. Reaping the benefits: Science and the sustainable intensification of global agriculture.

**Sadok, W. 2011.** Chapter Seven - Crops Yield Increase Under Water-Limited Conditions: Review of Recent Physiological Advances for Soybean Genetic Improvement. In L. S. Donald, V (Ed.), Advances in Agronomy, Vol. Volume 113: 325-349: Academic Press.

**Slafer et al**. 1994. Increases in grain yield in bread wheat from breeding and associated physiological changes. Genetic improvement of field crops. Book.

**Schutter, O. D.** 2011. The New Green Revolution: How Twenty-First-Century Science Can Feed the World. In V. G (Ed.): 33-44. Solutions 2 (4),.

**Séguin, B. 2011.** How could forest trees play an important role as feedstock for bioenergy production?, Current Opinion in Environmental Sustainability, Vol. 3: 90-94.

**Shyam-Singh, Y.** 2011. Crop Adaptation to Climate Change. In J. L. H. R. Redden, H. Lotze-Campen, A. Hall (Ed.), Section Regional Impacts: Europe: 632.

**Stuthman, D.** 2007. Breeding Crops for Durable Resistance to Disease. In L. S. Donald, D.,Leonard, K. J.,Miller Garvin, J. (Ed.), Advances in Agronomy, Vol. Volume 95: 319-367: Academic Press.

**Vanek, T**. 2010. Fine "green" chemicals from biomass.

**Zanetti, F.** 2009. Yield and oil variability in modern varieties of high-erucic winter oilseed rape (Brassica napus L. var. oleifera) and Ethiopian mustard (Brassica carinata A. Braun) under reduced agricultural inputs. In T. Vamerali, & G. Mosca (Eds.), Industrial Crops and Products, Vol. 30: 265-270.

# ANNEX 8: BIBLIOGRAPHY FOR ANNEX 2 OF THE REPORT


**Almekinders CJM and Elings A**(2001). Collaboration of farmers and breeders: Participatory crop improvement in perspective. Euphytica, 122, 3: 425-438.

**Altieri MA** (1995) Agroecology: The Science of Sustainable Agriculture, 2nd ed. Westview Press, Boulder, Colorado.

**Bocci, R. & Chable, V.** (2008). Les Réseaux Semences Paysannes en Europe et l'évolution des lois sur les semences - The Peasant Seeds Network in Europe and the evolution of seed laws. *Cahiers d'études et de recherche francophones/Agricultures*, *17*, 216-221.

**Ceccarelli S, Grando S, Singh M, Michael M, Shikho A, Al-Issa M, Al-Saleh A, Kaleonjy G, Al-Ghanem SM, Al-Hasan AL, Dalla H, Basha S, Basha T** (2003) A methodological study on participatory barley breeding. II. Response to selection. Euphytica, 133, 2: 185-200.

**Ceccarelli S, Grando S,Tutwiler R, Baha J,Martini AM Salahieh H, Goodchild A, Michael M** (2000). A methodological study on participatory barley breeding - I. Selection phase. Euphytica, 111, 2: 91-104.

**Chable V, Conseil M, Serpolay E, Le Lagadec F** (2008). Organic varieties for cauliflowers and cabbages in Brittany: from genetic resources to participatory plant breeding. Euphytica, 164: 521-529.

**Chable V, Kastler G, Kochko de P** (2011) Seed in transition: the trends of Participatory Plant Breeding and "Farmer Breeding" in France. Heuksalim Native Seed Institute. 17th IFOAM Organic World Congress. 26thSeptembre-4th October 2011 Seoul, Republic of Korea

**Rammel C, Stagl S, Wilfing H** (2007) Managing complex adaptive systems — A co-evolutionary perspective on natural resource management. Ecological economics 63: 9-21

**Darnhofer I, Bellon S, Dedieu B, Milestad R,** 2010, Adaptiveness to enhance the sustainability of farming systems. A review. Agronomy for sustainable development 30: 545–555

**De Schutter O, Vanloqueren G** (2011) The New Green Revolution: How Twenty-First-Century Science Can Feed the World. (July-August 2011) Solutions 2 (4), http://www.thesolutionsjournal.com

**Desclaux D, Ceccarelli S, Navazio J, Coley M, Trouche G, Aguirre S, Weltzien E, Lançon J** (2012). Centralized or decentralized breeding: The potentials of participatory approaches for low-input and organic agriculture. *In* : Lammerts van Bueren Edith T. (ed.), Myers James R. (ed.). Organic crop breeding. Chichester : Wiley-Blackwell [Royaume-Uni], p. 99-123.

**Desclaux D** (2005) Participatory plant breeding methods for organic cereals - Proceeding of the COST-SUSVAR/ECO-PB Workshop on Organic Plant Breeding strategies and the uses of molecular markers - 17-19 janvier 2005 – Driebergen –The Netherlands.

**Döring TF, Pautasso M, Finckh MR, Wolfe MS.** 2012. Concepts of plant health – reviewing and challenging the foundations of plant protection. Plant Pathology 61: 1-15

**Finckh MR** (2008) Integration of breeding and technology into diversification strategies for disease control in modern agriculture. Eur J Plant Pathol (2008) 121:399–409

**Finckh MR, Gacek ES, Goyeau H, Lannou C, Merz U, Mundt CC et al.** (2000). Cereal variety and species mixtures in practice, with emphasis on disease resistance. Agronomie, 20: 813–837.

**Ghaouti L., Vogt-Kaute W, Link W** (2008). Development of locally-adapted faba bean cultivars for organic conditions in Germany through a participatory breeding approach. Euphytica, 162, 2: 257-268.

**IAASTD** (2008). Executive Summary of the Synthesis Report of the International, Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). Available on http://www.agassessment.org. IFOAM (2005a). The Principles of Organic Agriculture, http://www.ifoam.org/about_ifoam/principles/index.html

**IFOAM** (2005b). Plant Breeding Draft Standards, http://www.ifoam.org

**Lammerts van Bueren ET, Struik PC** (2004) The consequences of the concept of naturalness for organic plant breeding and propagation. Neth J Agric Sci 52(1): 85–95.

**Lammerts van Bueren E T, van Soest LJM, de Groot LC, Boukema IW, Osman AM** (2005) Broadening the genetic base for better-adapted varieties for organic farming systems: participatory characterisation, evaluation and selection of onion accessions for new base populations. Euphytica, 146, ½: 125-132.

**Liang W** (1998) Farming systems as an approach to agro-ecological engineering. Ecological Engineering 11: 27–35.

**Machado AT, Fernandes M** (2001). Participatory maize breeding for low nitrogen tolerance. Euphytica, 122: 567-573.

**Osman A , Chable V** (2009) Inventory of initiatives on seeds of landraces in Europe. Journal of Agriculture and Environment for International Development (Formerly Rivista di Agricoltura Subtropicale e Tropicale) 103 (1/2): 95-130

**Osman A M, Almekinders CJM, Struik P C, Lammerts van Bueren E T** (2008) Can conventional breeding provide onion varieties that are suitable for organic farming in the Netherlands? E. T. Lammerts van Bueren, H. Østergård, I. Goldringer, O. Scholten, (Eds). Euphytica, 163, 3: 511-522.

**Rudebjer J, Baidu-Forson J, Van Schagen B, Jarvis A, Staver A, Hodgkin T** (2009) Agrobiodiversity and climate change: what do students need to know? Presented at: 2ND ANAFE International Symposium: Mainstreaming climate change into Agricultural Education: Tools, Experiences and challenge. 28th July-1st August, 2009, Cross Roads Hotel, Lilongwe, Malawi. Retrieved on 09/08/2012 http://www.bioversityinternational.org/fileadmin/bioversityDocs/Training/Agrobiodiversity_Education/

**Patto MCV, Moreira P.M, Almeida N, Satovic Z, Pego S.** (2008). Genetic diversity evolution through participatory maize breeding in Portugal. Euphytica, 161, ½: 283-291.

**Phillips SL, Wolfe MS** (2005) Evolutionary plant breeding for low input systems. Journal of Agricultural Science 143: 245-254

**Hajjar R, Jarvis DI, Gemmill-Herren B** (2008) The utility of crop genetic diversity in maintaining ecosystem services. A review. Agriculture, Ecosystems and Environment 123 : 261–270

**Ceccarelli S and Grando S** (2007) Decentralized-participatory plant breeding: an example of demand driven research. Euphytica 155:349–360.

**Sperling L. Ashby JA, Smith ME, Weltzien E, McGuire S** (2001) A framework for analyzing participatory plant breeding approaches and results. Euphytica, 122, 3: 439-450.

**Suneson CA.** 1956. An evolutionary plant breeding method. Agronomy Journal 48: 188–191.

**Thomas M, Demeulenaere E, Dawson, JC, Khan A-R, Galic N, Jouanne-Pin S, Remoue C, Bonneuil C and Goldringer I** (2012) On-farm dynamic management of genetic diversity: the impact of seed diffusions and seed saving practices on a population-variety of bread wheat. Evolutionary Applications Article first published online: 4 APR 2012 doi:10.1111/j.1752-4571.2012.00257.x

**Vanloqueren G, Baret PV** (2009) How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations. Research Policy 38: 971–983

**Vernooy R,** (2003). Seeds that give: Participatory Plant Breeding. IDRC, Canada (www.idrc.ca/seeds).

**Weltzien E, vom Brocke K, Toure A, Rattunde F, Chantereau J**(2008) Review and outlook for participatory plant breeding in West Africa. In: D. Bazile, E.Weltzien (Eds). Cahiers Agricultures, 17, 2: 165-171.

**Wolfe MS, Baresel JP, Desclaux D, Goldringer I, Hoad S, Kovacs G, Löschenberger F, Miedaner T, Østergård H, Lammerts Van Bueren ET** (2008) Developments in breeding cereals for organic agriculture in Europe. Euphytica 163: 323–346.

# ANNEX 9: SURVEY RESULTS: THE FUTURE OF PUBLIC PLANT BREEDING

Respondents to the survey questionnaire have been invited to answer the aspects their organisation considers the most limiting for the success of the public plant breeding programmes in 2000 and in 2012.

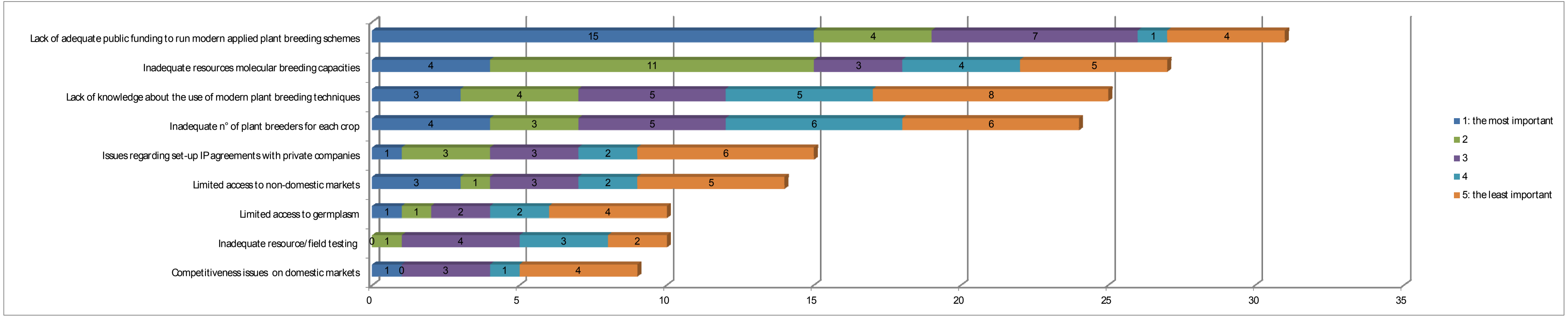
Answers that have been provided has been used to feed responses to several other questions of the survey questionnaire and therefore these results are not presented in a specific an unique section of this report.

Statistics of these results are as follows.

## Most limiting criteria for the success of public plant breeding programmes in 2000

Number of respondents: 33

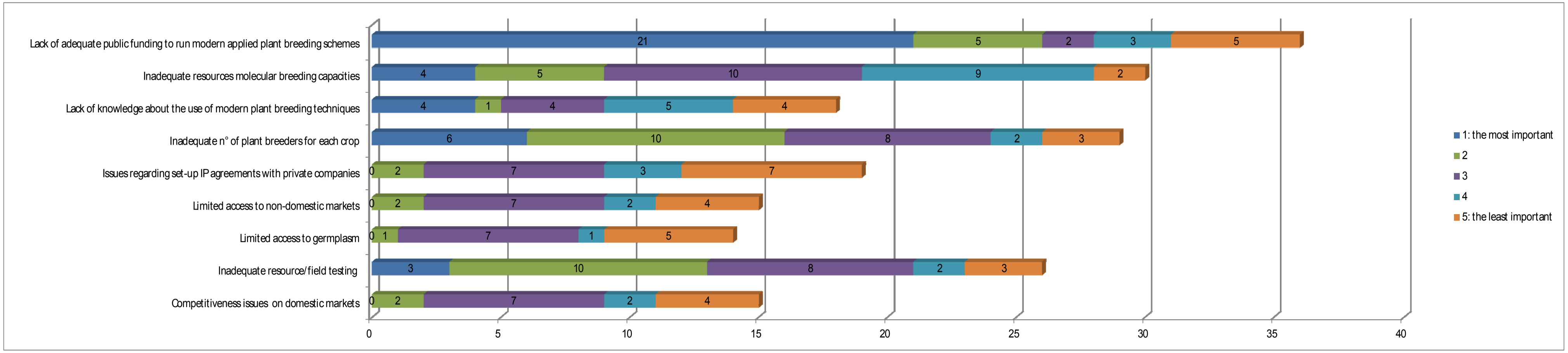
| | 1: the most important | 2 | 3 | 4 | 5: the least important |
|---|---|---|---|---|---|
| Competitiveness issues on domestic markets | 1 | 0 | 3 | 1 | 4 |
| Inadequate resource/field testing | 0 | 1 | 4 | 3 | 2 |
| Limited access to germplasm | 1 | 1 | 2 | 2 | 4 |
| Limited access to non-domestic markets | 3 | 1 | 3 | 2 | 5 |
| Issues regarding set-up IP agreements with private companies | 1 | 3 | 3 | 2 | 6 |
| Inadequate n° of plant breeders for each crop | 4 | 3 | 5 | 6 | 6 |
| Lack of knowledge about the use of modern plant breeding techniques | 3 | 4 | 5 | 5 | 8 |
| Inadequate resources molecular breeding capacities | 4 | 11 | 3 | 4 | 5 |
| Lack of adequate public funding to run modern applied plant breeding schemes | 15 | 4 | 7 | 1 | 4 |



## Most limiting criteria for the success of public plant breeding programmes in 2012

Number of respondents: 40

| | 1: the most important | 2 | 3 | 4 | 5: the least important |
|---|---|---|---|---|---|
| Competitiveness issues on domestic markets | 0 | 2 | 7 | 2 | 4 |
| Inadequate resource/field testing | 3 | 10 | 8 | 2 | 3 |
| Limited access to germplasm | 0 | 1 | 7 | 1 | 5 |
| Limited access to non-domestic markets | 0 | 2 | 7 | 2 | 4 |
| Issues regarding set-up IP agreements with private companies | 0 | 2 | 7 | 3 | 7 |
| Inadequate n° of plant breeders for each crop | 6 | 10 | 8 | 2 | 3 |
| Lack of knowledge about the use of modern plant breeding techniques | 4 | 1 | 4 | 5 | 4 |
| Inadequate resources molecular breeding capacities | 4 | 5 | 10 | 9 | 2 |
| Lack of adequate public funding to run modern applied plant breeding schemes | 21 | 5 | 2 | 3 | 5 |



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**Abstract**

The JRC Scientific Policy Report provides the results of a study on "Plant Breeding for an EU bio-based economy 2020" which was carried out by Arcadia International in 2012.

The study is based on a literature search, a workshop, interviews with experts and a survey directed at public breeding institutes. The first part of the study evaluates the breeding needs relevant for the bioecenomy strategy 2020 for food, feed, biofuel and biochemical uses and to what extent they are covered by the private breeding sector. The second part of the study investigates the capacity of public breeding institutes to fulfill breeding needs where the private sector is not investing sufficiently.

On the basis of the results of the study, the authors conclude that the capacity of public breeding in the EU is low and will not be able to fulfil the needs of the bioeconomy strategy 2020 which are currently not covered by the private sector. In Member States (e.g. PL or RO) where public breeders are still relevant competitors on the market, institutes mainly focus on agronomic traits only. In the other Member States, institutes concentrate mainly on genomic and pre-breeding activities complementing the activities of the private sector in applied plant breeding.

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